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PARALLEL TRIAL OF HIGH HORIZONTAL RESOLUTION GLOBAL NWP MODEL WITH TWO HOUR DATA CUTOFF

by

S J Lorrimer, O M Hammon and C A Wilson

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ABSTRACT

In this note we describe the trial of a high resolution global model (432x325, ~60km) run with a two-hour data cutoff. We compare the results with both the operational global model and the LAM. The analyses are always degraded, but the forecasts are frequently significantly improved in the northern hemisphere. The one exception to this is the wind field, which is significantly degraded. Tropical and southern hemisphere forecasts are also degraded. There is evidence to suggest that the degradation is due to the shortened data cutoff and that enhancing the global model resolution alone would be beneficial. However, in this trial, the overall impact is detrimental; the NWP index is reduced by 0.3. On this evidence, enhancing the global model resolution will not compensate for a reduction in the data cutoff time.

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1. INTRODUCTION

This trial was set-up as part of the project to progress the technical solution to the NWP user requirement. The project was tasked with three main objectives:

- To identify an optimal cut-off time. This is constrained by a user requirement to have products available soon after T+2h30m.
- Testing whether a global model with ~65km resolution could replace the LAM.
- Testing whether a single high resolution global model run could meet the requirements placed on both the LAM and global models.

These three requirements strongly influenced the design of this trial. Previous parallel trials (Wilson *et al* 1996, Lorrimer *et al* 1996) have already tested the impact of truncating the data cutoff with the present resolution. They tested cutoffs of 1h30m, 2h and 2h30m. These tests showed that there is no 'acceptable' data cutoff. Any shortening of the data cutoff leads to a significant degradation in the forecast, although the degradation from a 1h30m cutoff was particularly severe. However, to meet the user requirement, a 2h data cutoff was seen as the longest which was viable. Although this leads to degradations, we hoped that, when combined with a 60km global resolution, there would be, at worst, an overall neutral impact. The high resolution model could then replace the LAM.

The trial was, therefore, set up to test a high resolution model (432x325, or ~60km at mid-latitudes) with a two-hour data cutoff. If satisfactory, this set-up could replace both the LAM and global model runs. The trial was separated into two phases. The first (phase A), which lasted from 960523 to 960628, included two runs, at 12UTC and 00UTC, out to T+36. The second (phase B), which ran from 960702 to 960714, had a run only at 12UTC, but extended to T+72. Lack of resources prevented us testing the medium range.

Both phases of the trial were run at UM version 4.0, and the changes to the model were straightforward. However, we also made changes to the observation processing steps and a modification was required so that subsequent jobs would recognise the output as global model output. The physics timestep remained at 20 minutes (1200 seconds), but the dynamics timestep was reduced from 600 seconds to 400 seconds. New ancillary files were created for the new resolution. The diffusion constants were set to the values used for the LAM. The high resolution global model required more than 80Mw of memory and additional disk space increased.

Verification was not available for the full period as an extra interpolation step was required to verify the high resolution global model. The verification of the operational model is done on a 2.5° grid, following the CBS standard. To move the operational global model data from its own grids to the verification grid smoothing algorithms are used. These are grid specific and so we could not apply them directly to the high resolution model fields. We moved the high resolution data onto the operational grid using a bi-linear interpolation; the high resolution fields could then be smoothed as with the operational model. Debugging of the interpolation routine caused the loss of several days' verification. The first verification was not available until 960529. The interpolation plus smoothing procedure was a pragmatic solution to allow a parallel suite to be run. However, a better long term solution which removes the explicit dependance on the current grid needs to be determined.

A floating point exception also occurred twice during the trial. This revealed a hitherto undetected error in assimilation. It was due to an observation being exactly at a grid point; a divide by zero then results. A check for this was subsequently included in the trial, but before its inclusion the error caused the loss of the trial on 960618, 960619 and 960628.

Our report is in five sections. Section two deals with the impact of the data cutoff, section three with the subjective assessment and section four with the objective assessment (verification). Finally, in section five we summarise and discuss our conclusions.

2. Data Receipt

The number of observations available for the operational assimilation (cut-off at T+185) has been analysed in Table 2.1 below, together with the percentages of that data received in time for the trial assimilation (cut-off at T+120). A high percentage (>85%) of the synoptic data, (eg synops, ships, sondes), were received by T+120. A number of the asynoptic observations, (eg satellite data and aircraft reports) will be lost whatever cut-off time is used but a potential problem during this trial was the low number of 00Z AMDARS (47%) received by T+120.

TABLE 2.1

Total number of observations received by T+185 (operational cut-off), plus the percentage of those observations received by T+120 (trial cut-off) for A (period 23/05/96-28/06/96) and B (period 03/07/96-14/07/96)

OBS	A-DT00Z	A-DT00Z	A-DT12Z	A-DT12Z	B-DT12Z	B-DT12Z
	Total no obs rec'd by T+185	% obs rec'd by T+120	Total no obs rec'd by T+185	% obs rec'd by T+120	Total no obs rec'd by T+185	% obs rec'd by T+120
SYNOPS	107707	94	115043	95	52181	96
SONDES	13841	87	12363	85	5675	85
SHIPS	15318	91	15634	91	6934	91
SATOBS	86150	80	98998	79	46760	81
AIREPS	18159	76	25439	74	12357	75
AMDARS	61386	47	120451	76	46499	74
D. BUOY	16102	74	20627	76	9491	78

In Figure 2.1, the top diagram illustrates the distribution of 12Z synops received later than T+120 during the Phase B period, July 3rd -14th. The middle diagram shows the number of synops received at intervals between 90 and 200 minutes after 12Z for the northern hemisphere (north of 30N), the tropics (30N-30S) and the southern hemisphere (south of 30S). The bottom diagram shows the accumulated number of synops between 90 and 200 minutes after 12Z. Similarly, the same information is given in Figures 2.2 - 2.8 respectively for sondes, ships, 12Z AMDARS, 00Z AMDARS, AIREPS, SATOBS and drifting buoys. All the figures show the distribution of late 12Z observations during the Phase B period ,July 3rd-14th, but very similar charts were obtained for 00Z observations and also for Phase A of the trial.

In the northern hemisphere, the most significant data missed by the earlier cut-off at T+120 were AMDARS and AIREPS. The numbers of AMDARS between 12Z and 15Z were twice as large than between 00Z and 03Z, although three quarters were received by 14Z. The numbers of AMDARS between 00Z and 03Z were smaller, but only half were received by 02Z. The top diagrams in Figures 2.4 and 2.5 show that most of the AMDARS received after T+120 were from the North Atlantic and North America. During this trial, the late AMDARS and AIREPS had only a slight impact on the forecast jets, but they could become more important in the winter season. Similarly, the top diagram in FIGURE 2.6 indicates that most AIREPS received after T+120 were from the North Atlantic and North Pacific, whilst the middle graph shows a series of peaks of AIREP observations between T+120 and T+185. FIGURES 2.3 and 2.8 also

indicate that the early cut-off also meant that occasional ship and drifting buoy observations were missed in the trial assimilations.

Satellite data were most important in the tropics, with the top diagram in Figure 2.7 indicating that a large number of SATOBS from the GMS satellite were received between T+140 and T+150. These could have had a large impact on the analysis over the South Pacific, Indonesia and Australia.

In the Southern Hemisphere, the data received after T+120 included late synops (large peak of observations at T+135), GMS satellite observations (small peak at T+140),and drifting buoys. No figures were available about GLOSS, but the early cut-off would mean that a significant amount of GLOSS data was missed by the trial assimilation especially in the tropics and southern hemisphere.

3. Subjective Assessment of the Parallel Suite Trial

3.1 Phase A (23/05/96 - 28/06/96)

During Phase A of the trial, the high resolution global model was run twice a day from DT 00Z and DT 12Z out to T+36 and the trial forecasts were compared with the operational global and limited area model forecasts. The impact of the higher resolution on global model forecasts could be seen clearly in slightly deeper depressions and troughs, stronger jets and greater detail. However, the data differences due to the earlier cut-off, meant that there was some inconsistency associated with this impact especially in the Southern Hemisphere. During this section, the trial, operational global and limited area models will be referred to as HIRES, OPER AND LAM respectively.

3.1.1 Northern Hemisphere

In the northern hemisphere most differences at T+36 were small and due to changes in the position and depth of depressions and troughs rather than due to evolution changes.
In comparison with the operational global forecasts, the HIRES forecasts showed greater detail, including deeper depressions, sharper troughs, a tendency to form cut-off lows rather than elongated troughs, and also stronger jets. In comparison with the LAM, the HIRES forecasts showed slightly less detail.

a) Mean Sea Level Pressure Differences

The next three examples show some of the differences seen between HIRES, OPER and LAM forecasts over the North Atlantic during the trial.

i) T+36 forecast from DT 00Z 24th May 1996 - North Atlantic

The significant feature in the mean sea level pressure analysis for 12Z 25th May, Figure 3.1d, was a North Atlantic depression, 984hPa, centred at 52N 35W. All the forecasts, HIRES, OPER and LAM, forecast the position of the depression accurately at T+36, but the HIRES centre, Figure 3.1a, was slightly deeper and closer to the analysed centre 984hPa.

ii) T+36 forecast from DT 00Z 31st May 1996 - Newfoundland

The analysis for 12Z 01/06/96, Figure 3.2d , shows a small depression, 1002hPa, centred just to the northeast of Newfoundland. Again, the HIRES depression, 1004hPa, Figure 3.2a, was slightly deeper than the OPER centre, 1011hPa, Figure 3.2b.

iii) T+36 forecast from 00Z 29th May 1996 - North Atlantic

This case gives an example of the HIRES depression being less deep than the OPER centre, illustrating the slight inconsistency of the impact of the increased horizontal resolution, possibly due to data differences. In Figure 3.3d, the analysis for 12Z 30th May shows a deep depression, 980hPa, centred just west of Ireland. The HIRES T+36 forecast for this time, Figure 3.3a,shows a depression, 992hPa, centred over Northwest Ireland, centred too far north and not nearly deep enough. The OPER T+36 depression, Figure 3.3b, was 6hPa deeper and closer to the analysed depth but still centred too far north. The best forecast was from the LAM, Figure 3.3c, although there was still a positional error of the depression.

B) HIRES RAINFALL VERSUS LAM RAINFALL

Table 3.1 below shows that the HIRES rainfall forecasts for the U.K compared favourably with those from the LAM.

TABLE 3.1

Assessment of high resolution and LAM rainfall forecasts over the UK

	A	B	C
T+12	12	54	6
T+24	17	46	9
T+36	15	50	7

KEY : A - HIRES forecast more accurate than LAM
B - HIRES forecast similar to LAM
C - HIRES forecast less accurate than LAM

The HIRES forecasts scored well for the representation of weak fronts, which the LAM often lost and also for shower distribution, which was often too widespread in the LAM forecasts. Four examples of rainfall differences are described below.

i) T+36 forecast DT 00Z 4th June 1996 VT 12Z 5th June 1996

The radar image for 12Z 5th June, Figure 3.4a, shows a narrow band of rain over Northern England and Wales associated with a weak trough. There was also a very weak cold front over Western Scotland and the Irish Sea giving only small patchy amounts of rain. The HIRES and LAM forecasts for T+36, verifying at 12Z 5th June, are compared in Figures 3.4 b/c respectively. Neither forecast succeeded in forecasting the rain over Northern England and Wales. The HIRES model predicted the position of the weak cold front accurately but overdid the

amounts of rain.

ii) T+36 forecast DT 12Z 4th June 1996 VT 00Z 6th June 1996

The radar image for 00Z 6th June, Figure 3.5a, shows an area of rain over the Isle of Man and Eastern Ireland associated with a wave on a slow moving cold front. Most of the rain over Northern England was light and patchy. The HIRES forecast, Figure 3.5b, had a good representation of the weak front but the LAM forecast, Figure 3.5c, lost the front completely.

iii) T+36 Forecast, DT 12Z 6th June 1996 VT 00Z 8th June 1996.

An area of thundery rain over the Midlands, East Anglia and the Southeast of England gave heavy rain during the early hours of June 8th. The radar image, Figure 3.6a, shows the extent of the rain area at 00Z. The LAM forecast, Figure 3.6c, was poor, failing to predict the heavy rain over East Anglia. The HIRES forecast, Figure 3.6b, was much more accurate, although amounts of rain in the far southeast were probably over-predicted.

iv) T+24 Forecast, DT 12Z 25th June 1996 VT 12Z 26th June 1996

The radar image, Figure 3.7a, shows a very narrow band of rain associated with a trough lying from the Wash to Brest. Again, the LAM forecast, Figure 3.7c, completely lost the band of rain over England. The HIRES forecast, Figure 3.7b, had a better representation of the front, although the timing was about 3 hours slow.

c) HIRES JETS VERSUS GLOBAL AND LAM JETS IN THE NORTH ATLANTIC

The HIRES 250hPa jet maxima at T+36 were mostly stronger than corresponding OPER jet maxima. A comparison of 70 trial and operational North Atlantic jets which differed by more than $5ms^{-1}$ showed that 67 of the HIRES jets were stronger. The HIRES jet analyses were also slightly stronger.

The HIRES 250hPa jet maxima were closer to the LAM jet maxima or occasionally slightly stronger. A comparison of 64 HIRES and LAM North Atlantic jets which differed by $5ms^{-1}$ or more showed that 41 of the HIRES jets were stronger. The assessment came out evenly since the HIRES jets occasionally appeared too strong. Two comparisons of North Atlantic jets are described below.

i) T+36 forecast from DT 12Z 26th May 1996

The 250hPa wind isotach analysis for 00Z 28th May, Figure 3.8d, shows a strong northerly jet over the North Sea, with maximum wind speed 75-77 ms^{-1}. Both the OPER and the LAM forecasts for T+36, verifying at this time, (see Figures 3.8b/c respectively) were slightly weak and positioned over Eastern England rather than the North Sea. The HIRES forecast, Figure 3.8a, was the best forecast, both in position and strength.

ii) T+36 forecast from DT 00Z 31st May

The North Atlantic analysis for 12Z 1st June, Figure 3.9d, shows a strong northwesterly jet at 250hPa to the west of Ireland, with maximum wind speed $89ms^{-1}$. The T+36 forecasts verifying at this time from the HIRES, OPER and LAM forecasts are compared in Figures 3.9 a/b/c

respectively. The HIRES and LAM forecasts were similar, giving a good forecast of the maximum wind speed, although there was a small direction error. The OPER forecast was slightly weak.

3.1.2 SOUTHERN HEMISPHERE

The HIRES trial had a much larger impact in the Southern Hemisphere at T+36 with differences of 10-15 hPa between HIRES and OPER forecasts quite common. The results of the subjective assessment are summarised in Table 3.2 below. The significant differences were due mainly to changes in timing and in the depth and position of lows and troughs , but there were also a few evolution changes. The impact of the increased resolution was rather inconsistent in the Southern Hemisphere, possibly due to less data being used in the trial assimilation cycle. Although the main impact could be seen in deeper lows and troughs and increased detail, occasionally the reverse occurred.

TABLE 3.2

Assessment of significant differences in PMSL (>6hpa), and 500hpa height (>6dm) between high resolution and operational global models in the southern hemisphere at T+36

S.HEMISPHERE	A	B	C
MSLP T+36	69	39	68
500hPa HT T+36	34	11	28

KEY : A - HIRES forecast more accurate than OPER
B - HIRES and OPER both incorrect
C - HIRES forecast less accurate than OPER

The following four examples illustrate the inconsistent impact of the trial in the Southern Hemisphere.

(i) T+36 forecast from DT 00Z 11th June 1996 over the South Atlantic

This example was chosen to illustrate the extra detail forecast by the HIRES model on most occasions. The analysis for 12Z 12th June, Figure 3.10c, shows a complex depression in the South Atlantic at 40-50S 5W. The HIRES and OPER forecasts for T+36 verifying at this time are compoared in Figures 3.10 a/b respectively. The extra detail in the HIRES forecast was an improvement, with the double centre correctly predicted, although the northern centre was slightly over-deepened.

ii) T+36 forecast from DT12Z 14th June 1996 over Australia

The main feature in the analysis for 00Z 16th June, Figure 3.11c, was a depression, 996hPa, centred near the Great Australian Bight. On this occasion, the OPER T+36 forecast, FIGURE 3.11b, was much better than the HIRES forecast, Figure 3.11a. The HIRES forecast was poor, with the depression 10 degrees too far south and 17hPa too deep. There were errors in the OPER forecast, but it was clearly better than the HIRES forecast.

iii) T+36 forecast from DT00Z 18th June 1996 over Cape Horn and the Antarctic Peninsula

Many large differences in mean sea level pressure forecasts occurred at the southern tip of South America between Cape Horn and the Antarctic. The analysis for 12Z 19th June, Figure 3.12c, shows a depression centred over the Antarctic Peninsula. In this case, the position of the depression was slightly more accurate in the HIRES forecast, Figure 3.12a.

3.2 PHASE B (02/07/96 - 14/07/96)

During Phase B of the trial, the high resolution global model was run once a day from DT 12Z out to T+72 to check for changes in evolution between trial and operational forecasts. Changes in evolution in the Northern Hemisphere at T+72 were slight and the biggest impact was noticed in the Southern Hemisphere.

3.2.1 NORTHERN HEMISPHERE

In the Northern Hemisphere most differences at T+36 and T+72 were small and due to changes in the position and depth of depressions and troughs rather than due to evolution changes.

A) MEAN SEA LEVEL PRESSURE DIFFERENCES

i) Hurricane Bertha at 12z 12th July

Positive extra detail added by the higher horizontal resolution at T+72 included slightly deeper depressions and sharper troughs. The biggest success achieved by the HIRES model was in the prediction of Hurricane Bertha. Figure 3.13e shows the position of Bertha at 12Z 12th July, approximately three hours before it hit the coast of South Carolina. The top two charts in Figure 3.13, a/b, show the HIRES T+48 and T+72 forecasts verifying at 12Z 12th July. These can be compared to the bottom two charts, c/d, which show the corresponding OPER forecasts. This comparison shows clearly that the HIRES forecasts maintained a deeper and tighter circulation up to T+72. The predicted track was also better, with the HIRES forecasts steering Bertha on a track slightly further west towards land. Although the OPER forecasts maintained the centre, the circulation was much weaker and the steering less accurate. A full comparison, including details of the tropical cyclone verification, is given by Julian Heming in Appendix A.

ii) T+72 forecast from DT12Z 6th July over the Baltic sea.

In the vicinity of the U.K. differences were relatively small at T+72 and the charts in Figure 3.14 show a typical example. The mean sea level pressure analysis for 12z 9th July, Figure 3.14c, shows a depression, 994hPa, centred over the Baltic Sea, with a strong northerly airstream over Sweden. The HIRES and OPER T+72 forecasts verifying at 12Z 9th July are compared in Figures 3.14 a/b respectively. The OPER depression was centred slightly too far east over Lithuania, so the forecast winds over Sweden were too light. The HIRES depression was centred further west over Poland, with a stronger northeasterly winds over Sweden.

3.2.2 SOUTHERN HEMISPHERE

As in Phase A of the trial, the HIRES model had a much larger impact in the Southern Hemisphere and the results of the subjective assessment are summarised in Table 3.3 below.

TABLE 3.3

Assessment of significant differences in mslp (>6hpa), and 500hpa height (>6dm) between hires and operational global models in the southern hemisphere at T+72

S.HEMISPHERE	A	B	C
MSLP T+36	24	15	19
500hPa HT	12	7	9

KEY : A - HIRES forecast more accurate than OPER
B - HIRES and OPER both incorrect
C - HIRES forecast less accurate than OPER

The significant differences were due mainly to changes in timing and in the depth and position of lows and troughs , but there were also some evolution changes. Again the impact was inconsistent and the assessment worked out evenly. The following two examples illustrate the differences seen between HIRES and OPER T+36 forecasts in the Southern Hemisphere.

i) T+72 forecast from 12Z 8th July over Australia.

At 12z 11th July, the analysis in Figure 3.15c, shows a depression, 1010hPa, centred to the west of Australia. The T+72 forecasts from the HIRES model, Figure 3.15a, predicted the position of the depression fairly accurately but over-deepened it by 7hPa. In the OPER forecast, Figure 3.15b, the low was too shallow. A comparison of the HIRES and OPER 500HPa height forecasts for T+72 , Figures 3.16a/b respectively, shows that the 500hPa low was also slightly over-deepened in the HIRES forecast.

ii) T+72 forecast from 12Z 14th July over the South Atlantic.

In this final example, the HIRES T+72 500hpa height forecast for the South Atlantic, Figure 3.17a, over-deepened a small trough at 45S 15w.

3.3. CONCLUSIONS

- The early cut-off of data at T+120 in the HIRES model appeared to have a slightly detrimental impact on forecasts, especially in the Southern Hemisphere,where the impact was inconsistent.

- Impact was small in the Northern Hemisphere but there were some evolution changes in the Southern Hemisphere.

Positive benefits from the high horizontal resolution included;

- Better prediction of tropical cyclones
- Slightly deeper lows
- Troughs slightly sharper
- Slightly stronger jets
- Better representation of small scale features.
- Rainfall forecasts compared well against LAM.

Drawbacks from the high horizontal resolution in the Southern Hemisphere included;

- Occasional over-deepening of depressions and troughs
- Extra detail sometimes spurious

4. Objective Verification

4.1 Introduction

Forecasts were verified against analyses, upper air soundings, surface observations, AIREPs and AMDARs. Verification was available from 29th May 1996 to 2nd July 1996 for T+00, T+12, T+24 and T+36. From 3rd July 1996 to 14th July 1996 verification was available for T+00, T+24, T+48 and T+72. Comparisons with the operational LAM forecasts were made from 1st June 1996 to 14th July 1996.

We have divided the global verification into four areas: area 2, the northern hemisphere to 20N (NH), the tropics between 20N and 20S and the southern hemisphere from 20S (SH). For each field the bias and RMS have been found. The verification is complicated by a smoothing procedure. All fields are verified on a 2.5° grid, following the CBS standard. Data on the present model grids are moved on to the coarser CBS grid by smoothing algorithms, which are specific to the current operational global model grids[1]. So, the output of the high resolution model could not be directly input into the verification system. Consequently, we include a bi-linear interpolation to move the high resolution data on to the operational grid. The interpolated data is then smoothed and verified.

For the comparison with the LAM, the situation is simpler. The resolution of the LAM is approximately 50km, while at mid-latitudes the high resolution model has a resolution of 60km. These are similar enough to be directly comparable. Operationally, the LAM data is verified on its own grid without smoothing or interpolation. To compare the trial with the LAM we also verified the high resolution data on its own grid. 'LAM' verification was divided into two areas: the full LAM area and UK & Iceland

Verification was not available for the entire period due to a floating point exception in the assimilation scheme and difficulties with the verification scheme. In Table 4.1 we show those dates for which we could obtain verification of the smoothed high resolution fields. In the

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[1]A local numerical filter is applied. For future changes of horizontal grid this procedure needs to be removed and made to be more generally applicable.

first part of the trial, only one or other of the runs (12Z and 00Z) may have been missing. Also, some problems with the verification scheme affected the data on the height grid and not the wind grid, or *vice versa*. Therefore, a tick in Tables 4.1 only indicates that some verification data was available, not necessarily all of it.

TABLE 4.1

Verifying times and forecast ranges, for which objective verification for comparison with the operational global model was available during the parallel trial. The dates range from 960529 to 960714.

	29/5	30/5	31/5	01/6	02/6	03/6	04/6	05/6	06/6	07/6	08/6	09/6	10/6	11/6	12/6	13/6
T+00	✘	✔	✔	✔	✔	✘	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
T+12	✘	✔	✔	✔	✔	✘	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
T+24	✘	✘	✔	✔	✔	✘	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
T+36	✘	✘	✔	✔	✔	✘	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
T+48																
T+72																

	14/6	15/6	16/6	17/6	18/6	19/6	20/6	21/6	22/6	23/6	24/6	25/6	26/6	27/6	28/6	29/6
T+00	✘	✘	✘	✔	✔	✘	✘	✘	✔	✔	✔	✔	✔	✔	✘	✘
T+12	✘	✘	✘	✔	✔	✘	✘	✘	✔	✔	✔	✔	✔	✔	✘	✘
T+24	✘	✘	✘	✔	✔	✘	✘	✘	✔	✔	✔	✔	✔	✔	✘	✘
T+36	✘	✘	✘	✔	✔	✘	✘	✘	✔	✔	✔	✔	✔	✔	✘	✘
T+48																
T+72																

	30/6	01/7	02/7	03/7	04/7	05/7	06/7	07/7	08/7	09/7	10/7	11/7	12/7	13/7	14/7
T+00	✘	✘	✘	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
T+12	✘	✘	✘												
T+24	✘	✘	✘	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
T+36	✘	✘	✘												
T+48				✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
T+72				✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔

4.2 Comparison with Operational Global Model

4.2.1 RMS Errors Against Sondes and Surface Observations

Tables B.1-B.4, in Appendix B, summarise the percentage change in the RMS scores verified against upper air reports. We summarise surface observation verification in Table B.5. For T+12 and T+36 the scores come from phase A only. For T+00 and T+24 the second phase has also been included. A negative change indicates a reduction in the error in the trial forecast. All the verification that we discuss in this section shows the same general behaviour. In area 2 and the NH the trial is generally worse than or similar to the control at T+00. However, as the forecast progresses, the trial scores become significantly better. In the tropics and SH the trial scores are worse than operational at T+00; as the forecast proceeds the trial scores worsen further.

Table B.1 lists the percentage change in the RMS geopotential height errors out to T+36. In area 2 the trial shows a slight improvement at T+00 above 400hPa (Figure 4.1). As the forecast progresses this improvement is enhanced until, at T+36, the trial gives a significant improvement in height at all levels. The average improvement is -3.8%. The NH shows a similar trend, although in the NH the trial shows a deterioration at all levels at T+00 and smaller improvements at later forecast ranges; the improvement averages to -2.2% at T+36. In the tropics, the height analysis is significantly degraded, averaging at 1.0%, but reaching 1.9% at 300hPa. At later times this degradation reduces, so that the impact is neutral by T+36. In the SH the trial is much worse than the control. At T+00 levels below 300hPa are particularly badly affected, and this spreads to all levels by T+36. At T+36 the average deterioration is 10.2%, with a maximum of 14.6% at 700hPa. Phase B of the trial, which forecasts out to T+72, shows some contradictory signals (Figure 4.2). The improvements in area 2 do not increases at T+48 and T+72, and in the NH the scores below 300hPa are generally neutral at T+72. In the SH and tropics there are some significant improvements at T+48 and T+72. There are several possible explanations for the difference in the two phases. First, we derived the scores at T+48 and T+72 from a subset of the complete experiment. If the T+00 and T+24 scores are also derived only from that short period, they are not compatible with the mean scores for the whole period. So, this period may not be typical of the whole

experiment. Also, the second phase only had a run at 12Z, whereas the earlier phase includes runs at both 12Z and 00Z. However, there is no evidence that the scores at 12Z and 00Z are significantly different (see §4.2.4). Finally, phase A includes a period when the trial SH RMS height errors increase much more rapidly than the control errors (Figure 4.3). This looks very atypical, although we have no *a priori* reason for excluding the period.

Table B.2 lists the percentage improvements in the RMS temperature errors (see also Figure 4.4). The signal is very similar to the height errors, perhaps suggesting that much of the change in the height errors is due to changes in the temperature field. In area 2, at T+00 the change is generally positive, although with a significant degradation of 1.5% at 100hPa. By T+12 the trial is an improvement (typically ~-2%) below 50hPa, and this signal is maintained out to T+36. In the NH, the temperature analysis degrades by 1-2%. However, at 50hPa the degradation is 10.0%. As the forecast range increases, the scores improve, showing a -2% to -4% improvement by T+36. However, there is still a degradation of 5.6% at 50hPa. The tropics start with a very poor analysis of temperature, typically ~5% worse than the control. As the forecast range increases the degradation diminishes. At T+24 the trial is generally better than the control, although at T+36 the change is neutral. The SH shows a degradation of ~2% at T+00, T+12 and T+24. At T+36 the trial has degraded further to give ~4% larger RMS errors. The impact at 50hPa in the SH is consistently smaller than at other levels and fluctuates between positive and negative. For temperature, during phase B the trial is more in line with the total period. However, it still shows the SH in a more positive light; there is evidence of improvement in temperatures at middle levels (Figure 4.5). The anomalous period of verification mentioned above is also apparent in the temperature verification.

Table B.4 shows the percentage change in the trial RMS VWE's, compared with the control (see also Figure 4.6). The trends here are similar to those for height and temperature, but different in some important respects. In area 2 the change at T+00 is mixed, although at T+12 onwards there is an improvement in the trial of -1% to -2% at 250hPa and below. However, there is a persistent degradation of ~2.5% at 100hPa. In the NH the analysis deteriorates at all levels by 1.9-7.2%. There is some improvement at later times, but the improvements are never much greater than -1%. As in area 2, there is a persistent degradation at 100hPa. In the tropics the analysis is severely degraded. The trial RMS VWE's are typically ~15% greater in the trial than in the control. Although this degradation diminishes with time, it is still ~2% at T+36. The trends are similar in the SH, the analysis is degraded by less (~9%) but the degradation falls off less rapidly; at T+36 it is still ~7%. In the second part of the trial, the signal is very similar. At T+72, the winds virtually always degrade by 1-2%. The only exceptions to this are the tropical low level winds that improve by ~-0.5%.

The verification against surface observations (Table B.5) is more positively in favour of the trial. This is probably due to it benefitting from the high resolution orography. Nonetheless, the SH still shows a consistent deterioration of 3-6% at T+36. In other areas, including the tropics, there is an improvement of -1% to -2%. In phase B, the signal is more mixed. The change in the PMSL scores is detrimental in all areas and the negative impact in the SH is reducedfor the other fields.

To summarise the nett impact on the scores we have counted the number of scores which have changed by more than $\pm 1\%$. These are given in Table 4.2.

TABLE 4.2

Number of RMS scores verified against sondes and surface observations that have changed by more than 1% in the parallel trial (960529-960714) for T+00, T+12, T+24 and T+36.

Area	Trial better	Equal	Operational better	Total
Area 2	51	26	7	84
N Hemisphere	47	24	13	84
Tropics	13	37	34	84
S Hemisphere	2	20	62	84
Total	113	107	116	336

Table 4.2 shows that the trial is a clear improvement over the control in the NH and area 2. In the tropics and the SH the overall signal is clearly detrimental. The total scores are neutral. However, this enumeration takes no account of the relative importance of each area and the size of the detriment. Also, the improvements in area 2 enter the total twice, since this region is included in the NH.

4.2.2 VERIFICATION AGAINST ANALYSES

The verification against analysis shows similar trends to the verification against upper air reports and surface observations: area 2 and the NH start poorly and then improve, whereas the tropics and SH never recover from an even poorer start. However, this signal is less clear in the verification against analyses than it was in the verification against observations. Also, the recovery of the scores in the NH is poorer, leading to poor verification at later times. This is particularly significant as the NWP index (Table 4.4) is constructed from RMS scores against analysis.

The verification of height (Table A.6 and Figure 4.7) in area 2 at T+12 shows an improvement of -6% to -2% below 300hPa, but a deterioration of 4-6% above 100hPa. At T+36, the improvement is above 300hPa (-1% to -3%), with a deterioration of 3% below 700hPa. In the NH the signal as a function of forecast range is very confused. At T+12, the trial is generally detrimental, leading to a deterioration of 1.2-4.6% in most of the atmosphere. However, at T+24 the impact is an improvement at all levels, except 500hPa. By T+36 the verification has become very mixed and is difficult to characterise. The only consistent signals are the improvements at 850hPa and 50hPa. In the tropics, at T+12 the trial generally improves the verification. Improvements are typically -2% to -3%, although there are a couple of significant degradations. At T+24 the signal is mainly one of deterioration, although there are still some significant improvements of $\sim$-4% at 100hPa and 50hPa. By T+36 the signal is

mixed and again difficult to characterise. However, the deteriorations at 500hPa are maintained. In the SH the impact of the trial is highly detrimental. The RMS at all ranges and all levels deteriorates by 3-6%. There is no evidence of the degradation diminishing with forecast range. Phase B of the trial is not consistent with this; the height improves slightly in all areas, except very low levels. At the top of the atmosphere, the trial reduces the height errors by ~-10% at T+72 in all areas. As we commented before, we suspect that some height verification during phase A in the SH is incorrect and so the detriment in the SH may be over estimated.

In area 2, NH and SH the signal in the temperature verification (Table B.7 and Figure 4.8) is very similar to the height verification. However, in the tropics, the temperature verification is poorer than the height verification. At T+12 the tropical temperature verification is degraded by 2-8% at all levels except 500hPa, where there is a -2% improvement.

The verification of winds against analyses (Table B.9) is perhaps the poorest part of the trial. By T+36, the winds at all levels and in all areas deteriorate, the largest impact being 12.7% at 700hPa in the SH. Improvements at other times are extremely isolated. At T+12 there are improvements in area 2 of -3.2% at 850hPa and -1.0% at 700hPa. At the same time in the NH there is an improvement of -1.2% at 850hPa. By T+24 the only significant improvement is at 850hPa in area 2 (-1.4%, Figure 4.9). The verification of winds against analyses is particularly heavily weighted in the NWP index. The 250hPa wind at T+24 is included and this degrades by 1.8%, 4.4% and 7.2% in the NH, tropics and SH respectively. ***This alone is probably sufficient to conclude that we should not implement this configuration as a replacement for the current global model.*** Tropical 850hPa winds are also included in the NWP index; these show a small degradation of 0.4%. The deterioration in the wind verification extends beyond T+36 in phase B of the trial, although its amplitude is reduced. At T+72 the RMS VWE deteriorates by 2-6% in the trial (Figure 4.10).

As with the verification against observations, the verification of surface parameters (Table B.10) is largely favourable to the high resolution model. PMSL (Figure 4.11) is significantly degraded only in the SH, the degradation reaching 4.5% by T+36. The biggest improvement (-6.5%) is in area 2 at T+12. The 10m winds improve at T+12 in both area 2 (-3.1%) and the NH (-1.7%); in the tropics and SH they are degraded (1.5% and 3.0% respectively). At T+36 the 10m wind deteriorates in all areas. The worst area is the SH, where the degradation is 9.3%. The verification of the 1.5m temperature is overwhelmingly positive. Only at T+12 in the NH is there a degradation (3.1%). The largest improvement is in area 2 at T+24 (-5.4%).

To assess the general impact we have first enumerated those scores that change by more than 1% (Table 4.3). This clearly shows that the verification of the trial is overwhelmingly negative, especially in the SH

TABLE 4.3

Number of RMS scores verified against analyses that have changed by more than 1% in the parallel trial (960529-960714) for T+12, T+24 and T+36.

Area	Trial better	Equal	Operational better	Total
Area 2	37	25	25	87
N Hemisphere	21	27	39	87
Tropics	16	15	56	87
S Hemisphere	3	5	79	87
Total	77	72	199	348

Table 4.4 shows the impact of the trial on a proxy NWP index, $\bar{I}$, which is given by

$$\bar{I} = \frac{100}{\sum W_i} \sum W_i \frac{E_i}{\bar{\varepsilon}_i} \qquad (1)$$

where $\bar{\varepsilon}_i$ is the mean of the i^{th} score included in the index. Thus a positive number in the final column of Table 4.4 indicates a beneficial impact on the index of about that size. The T+24 components have been calculated using all the available runs - both 12Z and 00Z and both phases of the trial. The T+48 and T+72 components are based on phase B only. We are unable to estimate the T+96 and T+120 components, so the total weight is only 88. However, the normalisation ensures that the index still has a baseline of 100. On this basis the operational index is 129.7, while the trial index is 129.4, a degradation of 0.3. While this impact is small it is the result of a balance between some large improvements and degradations (Table 4.4). There are large deteriorations in the 250hPa winds and the SH 500hPa heights. Large improvements in NH PMSL balance these deteriorations.

TABLE 4.4

Table showing break down NWP index proxy into its constituent parts for the parallel and operational forecasts.

Area	Field	VT	W_i	E_i	$\overline{\varepsilon_i}$ control	$W_i E_i / \overline{\varepsilon_i}$ control	$\overline{\varepsilon_i}$ test	$W_i E_i / \overline{\varepsilon_i}$ test	$\Delta \overline{I}$
NH	PMSL	T+24	10	220.0	146.7	14.99	143.2	15.36	0.37
NH	PMSL	T+48	8	350.0	219.9	12.74	211.4	13.25	0.51
NH	PMSL	T+72	6	470.0	284.8	9.90	282.4	9.99	0.08
NH	H500	T+24	6	15.9	11.1	8.56	11.2	8.52	-0.04
NH	H500	T+48	4	28.8	19.0	6.05	19.0	6.07	0.01
NH	H500	T+72	2	42.8	27.2	3.15	27.4	3.12	-0.03
NH	W250	T+24	12	6.0	5.0	14.47	5.1	14.21	-0.26
Tropics	W850	T+24	5	3.3	2.5	6.68	2.8	6.65	-0.03
Tropics	W850	T+48	3	4.3	3.3	3.93	3.3	3.90	-0.04
Tropics	W850	T+72	2	5.0	3.9	2.57	3.9	2.55	-0.02
Tropics	W250	T+24	6	5.2	4.4	7.14	4.6	6.83	-0.30
SH	PMSL	T+24	5	290.0	287.4	5.04	291.6	4.97	-0.07
SH	PMSL	T+48	4	470.0	475.6	3.95	468.4	4.01	0.06
SH	PMSL	T+72	3	620.0	637.0	2.92	629.0	2.96	0.04
SH	H500	T+24	3	24.1	23.3	3.10	24.5	2.95	-0.15
SH	H500	T+48	2	42.4	43.9	1.93	43.8	1.94	0.00
SH	H500	T+72	1	59.5	63.0	0.95	62.6	0.95	0.01
SH	W250	T+24	6	6.3	6.2	6.09	6.7	5.68	-0.41

With a change as large as changing the resolution, the quality of the analysis can be significantly changed. An apparent deterioration in the quality of the forecast may be due to an improvement in the analysis. To test this we estimated the impact on the index using the verification against observations. The impact of each component on the index is estimated using

$$\frac{\delta \overline{I}}{I} = \frac{-\Sigma W_i \delta \overline{\varepsilon_i} / \overline{\varepsilon_i}}{\Sigma W_i} \qquad (2)$$

which can be derived from (1) using a number of simplifying assumptions. We do not require

the reference values, E_i, to calculate this. A break down of this is given in Table 4.5. Again a positive value in the final column of the table indicates a positive impact on the index. The nett impact is a reduction in this index of 0.3%. This is similar to the impact found using the verification against analysis. Also, the detriment is again due to the balance between improvements in PMSL and degradations in RMS VWE. Degradations in the SH 500hPa height are larger than against analysis.

TABLE 4.5

Table showing break down of NWP index proxy based on observations into its constituent parts for the parallel and operational forecasts.

Area	Field	VT	W_i	$\overline{\varepsilon_i}$ control	$\overline{\varepsilon_i}$ test	$\delta\overline{\varepsilon_i}$ (test-control)	$-W_i\delta\overline{\varepsilon_i}/\overline{\varepsilon_i}$
NH	PMSL	T+24	10	192.3	187.2	-5.1	0.27
NH	PMSL	T+48	8	242.7	236.6	-6.1	0.20
NH	PMSL	T+72	6	291.5	295.0	3.5	-0.07
NH	H500	T+24	6	18.4	18.2	-0.2	0.07
NH	H500	T+48	4	23.5	22.8	-0.7	0.12
NH	H500	T+72	2	29.1	28.8	-0.3	0.02
NH	W250	T+24	12	7.3	7.3	0.0	0.00
Tropics	W850	T+24	5	4.5	4.6	0.1	-0.11
Tropics	W850	T+48	3	5.3	5.2	-0.1	0.06
Tropics	W850	T+72	2	5.5	5.6	0.1	-0.04
Tropics	W250	T+24	6	7.0	7.2	0.2	-0.17
SH	PMSL	T+24	5	279.8	288.4	8.6	-0.15
SH	PMSL	T+48	4	400.8	390.7	-10.1	0.10
SH	PMSL	T+72	3	502.2	483.3	-18.9	0.11
SH	H500	T+24	3	30.3	32.9	2.6	-0.26
SH	H500	T+48	2	43.6	44.8	1.2	-0.06
SH	H500	T+72	1	56.4	56.2	-0.2	0.00
SH	W250	T+24	6	10.7	11.4	0.7	-0.39

4.2.3 VERIFICATION AGAINST AIREPS AND AMDARS

As with previous trials involving changes in data cutoff time (Wilson, Hammon & Leighton 1996, Lorrimer, Hammon & Wilson 1996) the impact on aviation forecasts is crucial and so the verification against AIREP's and AMDAR's has extra importance. These show similar

patterns to the verification of temperature and wind against other observation types. The NH and area 2 temperatures improve, while the tropical and SH temperatures deteriorate. The winds show a similar, but weaker, pattern.

The AIREP temperatures errors (Table B.11) show improvements in area 2, especially at 300hPa, where the improvement reaches -4.8% by T+36 (Figure 4.12). At greater altitudes the improvement is smaller. In the NH the pattern is similar, but in the tropics the temperatures are degraded. At T+00 the tropical temperature analysis has improved by up to -3%. However, as the forecast range increases the forecasts deteriorate until, at T+36, the forecast degrades by 3%. In the SH there are again improvements in analysis time at 250hPa and 200hPa (-1.4% and -1.2% respectively) although at 300hPa the RMS error is degraded by 1.3%. At later times all scores degraded, reaching a maximum at T+36 when the RMS increases by 1.5%, 5.8% and 11.7% at 300hPa, 250hPa and 200hPa respectively.

Verification of temperatures against AMDAR's (Table B.13 and Figure 4.13) follows broadly similar lines in area 2 and the NH, although the NH shows a consistent degradation of 6-7% at 100hPa. However, this based on only around 10 reports per run and so must be open to doubt. In the tropics there is a large degradation in the analysis above 300hPa, although at 700hPa there is a significant improvement. At later times this degradation reduces, until at T+36 there is a significant degradation only at 300hPa (2.8%). There are consistent improvements at 700hPa and 500hPa. In the SH there is again a consistent degradation at all levels and times, reaching 10.6% at 200hPa by T+36.

Verification of winds against AIREP's (Table B.12 and Figure 4.14) shows significant improvements by T+24 in both the NH and area 2 (typically -2% to -3%). However, at T+00 there are significant degradations (up to 1.9%). The improvements at T+24 contradicts the signal given by verification against upper air observations (Table B.4), where there was very little improvement at T+24, and in comparison with analyses (Table B.9), where there was generally a degradation. In the SH the trial has a neutral impact at T+00 and T+12. However, at T+24 and T+36 there are significant degradations. The analysis is severely degraded in the tropics (by 7.4% and 3.4% at 250hPa and 200hPa respectively). At later times there are significant improvements at 200hPa (up to -5.4%), but at 250hPa degradations of up 3.7% persist.

The verification of AMDAR winds (Table B.14 and Figure 4.15) shows a very different signal. In all areas the wind analysis deteriorates significantly, reaching 8.6% in the tropics at 300hPa. In area 2 the forecast recovers quickly from the degraded analysis so that by T+36 improvements of up to -5.1% are seen. The NH forecast also recovers from the degraded analysis, but the impact on the forecasts is never better than neutral. In the tropics the forecast recovers from the degraded analysis to some extent, but a degradation persists, reaching 8.4% by T+36 at 300hPa. In the SH all scores degrade. By T+36 the maximum degradation is 10.3% at 700hPa.

In summary, although there is some evidence of improved wind forecasts from higher

horizontal resolution, there is a consistent deterioration in both the tropics and SH. We suspect that this is largely as a result of the reduced data cutoff time compared to the operational.

4.2.4 COMPARISON OF 00Z AND 12Z RUNS

Table 2.1 shows that the truncated data cutoff (two hours) leads to a greater loss of AMDAR data in the 00Z run than in the 12Z run; for the 00Z run only 47% of AMDAR's were received, but for the 12Z run 76% were received. We have already noted that phase B, which included only a 12Z run, gave noticeably different verification to phase A, which included both 00Z and 12Z runs. We have verified the 00Z and 12Z runs from phase A separately to check for any significant differences. The impact on most scores at T+24 is similar for both runs. However, the verification of height against analysis does show some appreciable differences. In all areas the verification of the 12Z run (Figure 4.16) shows a larger beneficial impact than the 00Z run (Figure 4.17). However, the verification of the 12Z run during phase B (Figure 4.18) is closer to the verification of the phase A 00Z run than the phase A 12Z run. We cannot, therefore, conclude that the differences between phase A and phase B are due to the inclusion of a 00Z run in phase A; synoptic variability is the most likely reason.

4.2.5 BIASES

The global model biases are generally much improved. A particular point is that the NH upper troposphere cold bias significantly reduces, as do many height biases.

At analysis time, the height biases against radio sondes (Figure 4.19) have become more positive or less negative. This is generally an improvement, but has lead to small degradations in the tropical upper troposphere and the lower troposphere in area 2. At later times the improvement in the bias is generally retained, although the negative bias in the SH troposphere has been enhanced (Figure 4.20). Against analyses, the height biases reduce everywhere except the tropical upper troposphere. The improvement is especially marked in the SH, where the bias at 300hPa has been reduced to essentially zero (Figure 4.21).

In the tropics and SH the temperature biases against sondes are unchanged. However, in the NH and tropics there is a significant reduction in the upper troposphere cold bias (Figure 4.22). For instance in the NH at T+24 the cold bias reduces from -0.5K to around -0.3K. There are also improvements in the biases against analyses; they are present in all areas and at most levels (Figure 4.23) except the tropical lower troposphere. Particularly striking is the reduction of the cold bias in the SH troposphere. There is again evidence that the NH upper troposphere cold bias has been significantly reduced, from -0.3K to -0.2K.

At T+00 the wind speed bias is generally unchanged, except in the tropics above 200hPa, where there is a large reduction. In the NH and area 2 there is a significant reduction in the bias at later times (Figure 4.24). In the SH and tropics the already too weak winds are generally weaker still (Figure 4.25). When verifying against analyses the NH and area 2 generally have reduced biases, except at the lowest levels. However, for the tropics and SH the picture fluctuates between forecast ranges. However, a degradation is typical (Figure 4.26).

Verification of PMSL against surface observations shows that in the extratropics the biases have deteriorated. However, in the tropics the bias has improved by around 10Pa (Figure 4.27). Against analysis the verification is more positive (Figure 4.28). The biases usually reduce, except early times in the NH and late times in the SH. The change in the 1.5m temperature bias against observations is quite small. However, there is a general deterioration in the bias in the NH and area 2, and an improvement in the tropics and SH (Figure 4.29). When verifying against analysis there are small reductions in the screen temperature bias in all areas except the SH, where there are large deteriorations (Figure 4.30). Verification of 10m winds is quite similar to verification of screen temperatures. Against observations, the changes are small but show degradations in area 2 and the NH, and improvements in the tropics and SH (Figure 4.31). Against analyses the bias is always reduced except at late times in area 2 (Figure 4.32).

4.3 LAM Verification

4.3.1 Introduction

Here we compare the 60km global model with the operational LAM (50km), both verified on their own grids. The comparison is not strictly consistent as the set-up of the verification system prevented us verifying the two runs against the same sets of observations. However, we believe the main conclusiosn are still valid. We verified the LAM results from 960601 until 960714 using forecast ranges of T+00 (the analysis), T+12, T+24 and T+36. The forecasts were verified against upper air reports, surface observations and analyses. We have calculated the verification scores for two areas, the full LAM area and 'area 5' covering the UK & Iceland for both the LAM and the trial global model. Table 4.6 shows those dates on which the four forecast ranges considered could be verified.

TABLE 4.6

Verifying times and forecast ranges, for which objective verification for comparison with the operational LAM model was available during the parallel trial. The dates range from 960601 to 960714.

	01/6	02/6	03/6	04/6	05/6	06/6	07/6	08/6	09/6	10/6	11/6	12/6	13/6	14/6	15/6
T+00	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✘	✘
T+12	✔	✘	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✘	✘
T+24	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✘	✘
T+36	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✘	✘

	16/6	17/6	18/6	19/6	20/6	21/6	22/6	23/6	24/6	25/6	26/6	27/6	28/6	29/6	30/6
T+00	✘	✔	✔	✘	✘	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
T+12	✘	✔	✔	✘	✘	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
T+24	✘	✔	✔	✘	✘	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
T+36	✘	✔	✔	✘	✘	✘	✔	✔	✔	✔	✔	✔	✔	✔	✔

	01/7	02/7	03/7	04/7	05/7	06/7	07/7	08/7	09/7	10/7	11/7	12/7	13/7	14/7
T+00	✘	✘	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
T+12														
T+24	✘	✘	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
T+36														

4.2.1 RMS ERRORS AGAINST SONDES AND SURFACE OBSERVATIONS

The comparison of the verification of the high resolution model with that of the LAM shows similar trends to the comparison with the global model verification; the analysis deteriorates, but the forecast quickly recovers to show significant benefits by T+36. Compared to the LAM however, the improvements in the forecast from the high resolution global model are much greater.

At T+00 the RMS height errors (Table C.1) are quite strongly degraded, the worst being at 100hPa in the full LAM area (3.5%) and at 700hPa in the UK & Iceland area (5.8%). However, by T+12 the trial is usually an improvement on the control. The maximum improvement is -5.5% at 250hPa in UK & Iceland. By T+36, the trial improves the height scores in both areas and at all levels. The typical improvement is around -10% (Figure 4.33).

The RMS temperature errors (Table C.2 and Figure 4.34) show some improvement at T+00 (up to -8% at 250hPa), but also some significant degradations (reaching 7.6% at 100hPa over the full area). However, by T+12 these have almost completely gone, the only degradation being 3.6% at 500hPa in UK & Iceland. At all other levels the scores are improved or not significantly changed. By T+36 all the scores improve (by up to -10.1%, but typically by around -5%) but one; at 100hPa in the full LAM area there is no change in the score.

The impact on the wind verification (Table C.4 and Figure 4.35) is very similar to the impact on the temperature verification. At T+00 there are some significant degradations in the RMS VWE's. In particular, for the full LAM area, there is a degradation of 6.8% at T+00 and 100hPa. However, there are also some minor improvements of up to -1.7% at this time. As the forecast progresses the impact of the trial becomes increasingly positive. This is especially true for the full LAM area, where the improvements reach -7.9% at 300hPa. Of some concern, however, are the 100hPa winds, which, for the full LAM area, are consistently degraded by the trial.

The most worrying aspect of this comparison is the surface verification (Table C.5). PMSL verification shows similar trends to the other verification; the analysis degrades, but by T+36 the trial shows significant improvements. However, the 1.5m temperature verification shows large degradations at all times and in both areas; these reach 17.3% in UK & Iceland (Figure 4.36). The 10m wind verification is more mixed (also Figure 4.36). For the full LAM area, there are large improvements for all times, including T+00. However, for the UK & Iceland area, there are degradations at all times. However, the degradations are much smaller than the improvements.

4.2.2 Verification Against Analyses

The verification against analysis gives a very different signal to the verification against observations. While in the verification against observations the forecast frequently improves significantly by T+12, when verifying against analysis the forecast shows significant degradations at both T+12 and T+24. Any general improvement only becomes apparent at T+36.

The height verification (Table C.6) is particularly poor. At T+12 there are large degradations, reaching 14.3% at 300hPa in the full LAM area. In the full LAM area scores there are also some significant improvements. At T+24 the degradations are smaller, peaking at 5.6% in the UK & Iceland area, but some improvements have been lost since T+12. Only at T+36 can the overall impact be described as an improvement. In the full LAM area most of the levels improve (peaking at -21.6% at 100hPa, Figure 4.37). In UK & Iceland all but one level (100hPa) shows improved scores.

At T+12 the temperature verification (Table C.7 and Figure 4.38) is similar to the height verification: most of the levels show some deterioration, but a few show an improvement. However, for temperatures, the deteriorations at lower levels are quite persistent. For instance, for the full area at 850hPa the RMS error deteriorates by 8.8%, 3.7% and 2.3% at T+12,

T+24 and T+36 respectively. However, above 300hPa there some consistent improvements, peaking at -14.9% at 100hPa in the full LAM area. The scores in the UK & Iceland area show a similar trend to those in the full LAM area, but it is less extreme, so that by T+36 the impact might be described as neutral or slightly positive.

The RMS VWE's (Table C.9) are generally improved at T+12 in the full LAM area. This positive impact amplifies by T+24 and T+36 (Figure 4.39). The maximum improvement at T+36 is -9% at 200hPa. However, there is also a consistent deterioration at 500hPa of up to 3.1%. In the UK & Iceland area the T+12 forecast shows significant degradation below 300hPa. However, most of this degradation does not persist at T+24 and the forecast is wholly improved by T+36.

Verification of surface parameters (Table C.10 and Figure 4.40) usually shows a degradation. The only exceptions to this are: the verification of PMSL over the full LAM area, which shows improvements of -2.6%, -0.1% and -1.2% at T+12, T+24 and T+36 respectively; in the UK & Iceland area at T+36 there are improvements of -9.8% in PMSL and -2.6% 10m RMS VWE. The 1.5m temperatures have been particularly badly degraded, showing degradations of 8.6%-13.7%.

4.3.1 Comparison of Smoothed and Unsmoothed verification

To compare the verification of the high resolution global model with that of the operational global model, the high resolution data had to be first interpolated onto the standard grid. It was then smoothed on to a 2.5° grid. To compare the trial with the LAM, the trial had to be verified on its own grid. This trial therefore allows to consider the importance of smoothing on verification scores.

The importance of the smoothing is shown particularly well by the verification of sonde temperatures. Figure 4.41 shows the verification of the operational global model (solid line) and the high resolution model (dashed line) at T+00 over the full LAM area and UK & Iceland. The fields used in this verification have been smoothed on to a 2.5° grid. In both areas the RMS errors are very similar. We also show the LAM errors (dotted line) and the errors found when the high resolution model is verified on its own grid (dot-dashed line). Again, the two RMS error profiles are very similar. However, the verification of smoothed and unsmoothed fields is very different. Indeed, this is more important than the model type (LAM or high resolution global) or the model resolution. The smoothed RMS errors are not consistently lower than the unsmoothed errors, as one might have expected. Clearly, the smoothing of the fields is the most significant factor in determining the size of the RMS errors. This is why we have chosen to emphasise the results from the high resolution model when verified on its own grid and compared with the LAM. Both of these forecasts are made with similar data cutoffs, T+2h and T+1h50m respectively. The general improvement from the high resolution run is believed to come from the use of up-to-date 'boundary' forcing over the LAM area; for the operational LAM run lateral boundaries are from the global runs 12 hours previous and so do not have the benefit of the latest observational data.

4.3 Summary and Discussion of Verification

The most important points to note from the verification are:

- The verification of the analyses deteriorates.
- Most of the global forecasts improve against observations, but this is not true of the winds.
- Verification against analyses appears more mixed.
- Our best estimate of the NWP index suggests that the trial reduces it by 0.3. A measure based verification against observations shows that the index will decline by 0.3%.Most biases improve, especially the NH upper troposphere cold bias, which reduces by about one-third.
- The LAM analyses also deteriorate, but the improvement of the high resolution forecasts, relative to the LAM forecasts, is dramatic. The reason for the deterioration in the LAM analyses is not clear.
- The most significant factor in determining the size of the RMS error is the smoothing applied to the field prior to verification.

The reason for the deterioration in the analyses is clear: the reduced data cutoff time allowed fewer data to be assimilated and so deteriorated the analysis. Lorrimer, Hammon & Wilson tested the impact of a two hour cutoff with the current operational resolution. The size of the impact on the RMS score was similar to those found here at T+00, although the tests were run at different times. The similarity in the tropics is particularly striking. The later improvement in the forecasts is then due to the enhanced resolution. However, the winds do not recover. Table 2.1 shows that AMDAR's are the biggest single loss due to shortening the data cutoff time and these have a particularly large influence on jet level wind forecasts. It is the deterioration in winds which is mainly responsible for the deterioration in the NWP index. It is clear that enhancing the resolution of the model does not compensate for the impact of truncating the data cutoff time.

The LAM forecasts improve particularly dramatically. We believe that this due to the effect of boundary conditions. Operationally, the LAM uses boundary conditions which have been generated by the global model run 12 hours previously. So, the 00Z LAM forecast uses boundary conditions based on the earlier 12Z global model. When running the high resolution global model we are effectively using boundary conditions generated using the same data time as the limited area forecast. The deterioration of the high resolution analyses relative to the LAM analyses is more of a puzzle. The only difference between the two runs which might have caused this is the slightly better resolution in the LAM (50km versus 60km). However, this seems unlikely.

5 Summary and Discussion

The high resolution forecasts are generally better than their operational counterparts (both LAM and global) in the NH and area 2. This was apparent in both the subjective assessment and the verification against observations. The improvement in the verification over the global model is ~2% and over the LAM is ~5%. The subjective assessment highlighted the better

prediction of tropical cyclones (especially Hurricane Bertha), deeper lows, stronger jets and better rainfall forecasts. The extra detail was usually beneficial, but occasionally seemed spurious. In the SH and tropics, and at analysis time in all areas, there were large degradations in the verification against observations (frequently $\sim 10\%$). The subjective assessment in the SH was inconsistent and there were often large differences between the high resolution and control forecasts. Most of the effects are consistent with the analysis having been degraded by the truncated cutoff time. In the NH, where the degradation of the analysis was less severe, the use of high resolution then allows the forecast to recover by T+12. The critical exception to this is the wind field. Even in the NH, the winds are still worse than operational at T+24. This is probably still consistent with the impact of the early data cutoff. The biggest losses in data volume, when truncating the data cutoff, are the asynoptic AMDAR's and AIREP's, which have a major influence on the analysis of winds, especially at jet levels.

It is interesting to compare this trial with the work of Lorrimer *et al* (1996), who tested a two-hour cutoff with the current operational resolution. A direct comparison is not possible as the operational resolution trial took place in February and March. Hence, the synoptic conditions were different. However, a comparison of the general trends may be useful. The beneficial impact of the high resolution run is clear if we compare the calculation of the NWP index proxy in the two cases (Table 4.4 of this report and Table 3.4 of Lorrimer *et al*). In the operational resolution test, all components except tropical 850hPa winds and SH PMSL are degraded. However, at high resolution, the NH PMSL was significantly improved. During the high resolution trial the tropical and SH winds deteriorated by more than during the operational resolution trial. We suspect that the difference in the wind verification is due to the trials being run in different seasons. Most of the other changes are very similar. The nett impact on the NWP index is -0.3 in the high resolution trial and -0.7 in the operational trial. Although the nett impact is smaller in the high resolution trial, the difference in the trials is small and clearly moving to higher resolution has not compensated for shortening the data cutoff time.

The comparison of the high resolution global model with the LAM is very encouraging. At T+12 and beyond there are $\sim 5\%$ improvements in the verification and the subjective assessment has shown some clear improvements, especially the rainfall. Much of this improvement is probably due to the improved 'boundary conditions'. For the operational LAM forecast, the boundary conditions are derived from a global model run twelve hours earlier. Using the high resolution model eliminates this problem. More of a puzzle is the deterioration of the high resolution analyses compared with the LAM analyses. The resolution of the two models is very similar and so should not be a factor. However, there are some potentially important differences in the assimilation scheme: the LAM uses a shorter time ramp and a three hour assimilation cycle; the LAM will assimilate 03Z, 09Z, 15Z and 21Z SYNOP's, which will not be included in the global model; and the LAM timestep is shorter, which will improve the assimilation. Finally, the verification of the analysis is not necessarily a good indicator of the quality of the analysis.

To summarise, this trial shows that an enhanced global model resolution cannot compensate for a truncation in data cutoff time. In particular, the forecast of jet level winds is

severely degraded. We do not believe that a high resolution global model with a T+2h cutoff is a suitable replacement for the present operational resolution with a T+3h05m cutoff. However, there is good evidence that using a high resolution model without altering the data cutoff time will lead to significant improvements in forecast quality relative to both the current global model and LAM. Some further experiments suggest themselves. These include: a parallel trial of a high resolution model with the operational data cutoff; an assessment of the impact of providing mesoscale model boundaries from the high resolution model; experiments re-tuning the assimilation scheme to provide a better analysis; and, once the T3E is available, combined tests of high horizontal and vertical resolution.

ACKNOWLEDGEMENTS

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Lorrimer, S.J., Hammon, O.M. & Wilson, C.A., 1996, 'Parallel Trial of T+120 Minute and T+150 Minute Data Cutoffs in the Global Model.', NWP Technical Note No. 191.

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FIGURE CAPTIONS

All section 2 figures relate to phase B.

Figure 2.1 top - Location of 12Z synops received after 14Z (T+120) **centre** - Number of synops and time of receipt T+90-T+200 minutes after 12Z for the Northern Hemisphere (N of 30N), Tropics (30N - 30S), and Southern Hemisphere (S of 30S) **bottom** - Accumulated total synops and time of receipt.

Figure 2.2 as Figure 2.1 but for 12Z sondes

Figure 2.3 as Figure 2.1 but for 12Z ships

Figure 2.4 as Figure 2.1 but for 12Z AMDARS

Figure 2.5 as Figure 2.1 but for 00Z AMDARS

Figure 2.6 as Figure 2.1 but for 12Z AIREPS

Figure 2.7 as Figure 2.1 but for 12Z SATOBS

Figure 2.8 as Figure 2.1 but for 12Z drifting buoys

Figure 3.1 a) T+36 mean sea level pressure forecast for the North Atlantic from the HIRES model, DT 00Z 24/05/96 VT 12Z 25/05/96. b) As a but from the OPER model. c) As b but from the LAM. d) Verifying OPER mean sea level pressure analysis for 12Z 25/05/96.

Figure 3.2 a) T+36 mean sea level pressure forecast for the East Atlantic from the HIRES model, DT 00Z 31/05/96 VT 12Z 01/06/96. b) As a but from the OPER model. c) As b but from the LAM. d) Verifying OPER mean sea level pressure analysis for 12Z 01/06/96.

Figure 3.3 a) T+36 mean sea level pressure forecast for the North Atlantic from the HIRES model, DT 00Z 29/05/96 VT 12Z 30/05/96. b) As a but from the OPER model. c) As b but from the LAM. d) Verifying OPER mean sea level pressure analysis for 12Z 30/05/96.

Figure 3.4 a) Radar imagery for 12Z 05/06/96. b) T+36 mean sea level pressure and rainfall rate forecast for the UK from the HIRES model, DT 00Z 04/06/96 VT 12Z 05/06/96. c) As b but from the OPER model.

Figure 3.5 a) Radar imagery for 00Z 06/06/96. b) T+36 mean sea level pressure and rainfall rate forecast for the UK from the HIRES model, DT 12Z 04/06/96 VT 00Z 06/06/96. c) As above but from the OPER model.

Figure 3.6 a) Radar imagery for 00Z 08/06/96. b) T+36 mean sea level pressure and rainfall rate forecast for the UK from the HIRES model, DT 12Z 06/06/96 VT 00Z 08/06/96. c) As above but from the OPER model.

Figure 3.7 a) Radar imagery for 12Z 26/06/96. b) T+24 mean sea level pressure and rainfall rate forecast for the UK from the HIRES model, DT 12Z 25/06/96 VT 12Z 26/06/96. c) As above but from the OPER model.

Figure 3.8 a) T+36 250hPa wind isotach forecast for the UK area from the HIRES model DT 12Z 26/05/96 VT 00Z 28/05/96. b) As a but from the OPER model. c) As b but from the LAM. d) Verifying LAM 250hPa wind isotach analysis for 00Z 28/05/96.

Figure 3.9 a) T+36 250hPa wind isotach forecast for the UK area from the HIRES model DT 00Z 31/05/96 VT 12Z 01/06/96. b) As a but from the OPER model. c) As b but from the LAM. d) Verifying LAM 250hPa wind isotach analysis for 12Z 01/06/96.

Figure 3.10 a) T+36 mean sea level pressure forecast for the South Atlantic from the HIRES model, DT 00Z 11/06/96 VT 12Z 12/06/96. b) As a but from the OPER model. c) Verifying OPER mean sea level pressure analysis for 12Z 12/06/96.

Figure 3.11 a) T+36 mean sea level pressure forecast for South Australia from the HIRES model DT 12Z 14/06/96 VT 00Z 16/06/96. b) As a but from the OPER model. c) Verifying OPER mean sea level pressure analysis for 00Z 16/06/96.

Figure 3.12 a) T+36 mean sea level pressure forecast for the Antarctic Peninsular from the HIRES model, DT 00Z 18/06/96 VT 12Z 19/06/96. b) As above but from the OPER model. c) Verifying OPER mean sea level pressure analysis for 12Z 19/06/96.

Figure 3.13 a) T+48 mean sea level pressure forecast for Hurricane Bertha from the HIRES model, DT 12Z 10/07/96 VT 12Z 12/07/96. b) T+72 mean sea level pressure forecast for Hurricane Bertha from the HIRES model, DT 12Z 09/07/96 VT 12Z 12/07/96. c) As a but from the oper model. d) As b but from the oper model. e) Verifying oper mean sea level pressure analysis showing the position of Hurricane Bertha at 12Z 12/07/96.

Figure 3.14 a) T+72 mean sea level pressure forecast for the Northwest Europe from the HIRES model, DT 12Z 06/07/96 VT 00Z 09/07/96. b) As above but from the OPER model. c) Verifying OPER mean sea level pressure analysis for 00Z 09/07/96.

Figure 3.15 a) T+72 mean sea level pressure forecast for Southwest Australia from the HIRES model DT 12Z 08/07/96 VT 12Z 11/07/96. b) As above but from the OPER model. c) Verifying OPER mean sea level pressure analysis for 12Z 11/07/96.

Figure 3.16 a) T+72 500hPa height forecast for Southwest Australia from the HIRES model DT 12Z 08/07/96 VT 12Z 11/07/96. b) As above but from the OPER model. c) Verifying OPER mean sea level pressure analysis for 12Z 11/07/96.

Figure 3.17 a) T+72 mean sea level pressure forecast for the South Atlantic from the HIRES model DT 12Z 14/07/96 VT 12Z 17/07/96. b) As above but from the OPER model. c) Verifying OPER mean sea level pressure analysis for 12Z 17/07/96.

Figure 4.1 The percentage change in the RMS height errors verified against upper air reports at T+00 (phases A and B) and T+36 (phase A only) in area 2, the NH, the tropics and the SH. The dotted vertical lines are at $\pm 1\%$, which is considered the limit of practical significance.

Figure 4.2 The percentage change in the RMS height errors verified against upper air reports at T+72 (phase B only) in area 2, the NH, the tropics and the SH. The dotted vertical lines are at $\pm 1\%$, which is considered the limit of practical significance.

Figure 4.3 Time series of 500hPa RMS height errors and biases at T+12 in the SH. All T+12 forecasts verifying at 00Z have been used. The dashed line is the trial and the solid line is the control.

Figure 4.4 The percentage change in the RMS temperature errors verified against upper air reports at T+00 and T+24 in area 2, the NH, the tropics and the SH. The dotted vertical lines are at ±1%, which is considered the limit of practical significance.

Figure 4.5 The percentage change in the RMS temperature errors verified against upper air reports at T+00, T+24, T+48 and T+72 (phase B only) in the SH. The dotted vertical lines are at ±1%, which is considered the limit of practical significance.

Figure 4.6 The percentage change in the RMS VWE verified against upper air reports at T+00 and T+24 in area 2, the NH, the tropics and the SH. The dotted vertical lines are at ±1%, which is considered the limit of practical significance.

Figure 4.7 The percentage change in the RMS height errors verified against analyses at T+24 in area 2, the NH, the tropics and the SH. The dotted vertical lines are at ±1%, which is considered the limit of practical significance.

Figure 4.8 The percentage change in the RMS temperature errors verified against analyses at T+24 in area 2, the NH, the tropics and the SH. The dotted vertical lines are at ±1%, which is considered the limit of practical significance.

Figure 4.9 The percentage change in the RMS VWE verified against analyses at T+24 in area 2, the NH, the tropics and the SH. The dotted vertical lines are at ±1%, which is considered the limit of practical significance.

Figure 4.10 The percentage change in the RMS VWE verified against analyses at T+72 (phase B only) in area 2, the NH, the tropics and the SH. The dotted vertical lines are at ±1%, which is considered the limit of practical significance.

Figure 4.11 The percentage change in the RMS PMSL errors verified against analyses in area 2, the NH, the tropics and the SH. The dotted horizontal lines are at ±1%, which is considered the limit of practical significance.

Figure 4.12 The percentage change in the RMS temperature errors verified against AIREP's at T+00 and T+36 in area 2, the NH, the tropics and the SH. The dotted vertical lines are at ±1%, which is considered the limit of practical significance.

Figure 4.13 The percentage change in the RMS temperature errors verified against AMDAR's at T+00 and T+36 in area 2, the NH, the tropics and the SH. The dotted vertical lines are at ±1%, which is considered the limit of practical significance.

Figure 4.14 The percentage change in the RMS VWE verified against AIREP's at T+00 and T+36 in area 2, the NH, the tropics and the SH. The dotted vertical lines are at ±1%, which is considered the limit of practical significance.

Figure 4.15 The percentage change in the RMS VWE verified against AMDAR's at T+00 and T+36 in area 2, the NH, the tropics and the SH. The dotted vertical lines are at ±1%, which is considered the limit of practical significance.

Figure 4.16 The percentage change in the RMS height errors and biases verified against upper air reports at T+24 in area 2, the NH, the tropics and the SH. Only forecasts with data times of 12Z are included. The dotted vertical lines are at ±1%, which is considered the limit of practical significance.

Figure 4.17 The percentage change in the RMS height errors and biases verified against upper air reports at T+24 in area 2, the NH, the tropics and the SH. Only forecasts with data times of 00Z are included. The dotted vertical lines are at ±1%, which is considered the limit of practical significance.

Figure 4.18 The percentage change in the RMS height errors verified against upper air reports at T+24 (phase B only) in area 2, the NH, the tropics and the SH. The dotted vertical lines are at ±1%, which is considered the limit of practical significance.

Figure 4.19 The height biases verified against upper air reports at T+00 in area 2, the NH, the tropics and the SH. The solid line is the operational value and the dashed line is the trial value.

Figure 4.20 The height biases verified against upper air reports at T+36 in area 2, the NH, the tropics and the SH. The solid line is the operational value and the dashed line is the trial value.

Figure 4.21 The height biases verified against analyses at T+36 in area 2, the NH, the tropics and the SH. The solid line is the operational value and the dashed line is the trial value.

Figure 4.22 The temperature biases verified against upper air reports at T+00 and T+24 in area 2 and the NH. The solid line is the operational value and the dashed line is the trial value.

Figure 4.23 The temperature biases verified against analyses at T+24 in area 2, the NH, the tropics and the SH. The solid line is the operational value and the dashed line is the trial value.

Figure 4.24 The wind speed biases verified against upper air reports at T+00 and T+24 in area 2 and the NH. The solid line is the operational value and the dashed line is the trial value.

Figure 4.25 The wind speed biases verified against upper air reports at T+00 and T+12 in the tropics and SH. The solid line is the operational value and the dashed line is the trial value.

Figure 4.26 The wind speed biases verified against analyses at T+24 in area 2, the NH, the tropics and the SH. The solid line is the operational value and the dashed line is the trial value.

Figure 4.27 The PMSL biases verified against surface observations in area 2, the NH, the tropics and the SH. The solid line is the operational value and the dashed line is the trial value.

Figure 4.28 The PMSL biases verified against analyses in area 2, the NH, the tropics and the SH. The solid line is the operational value and the dashed line is the trial value.

Figure 4.29 The 1.5m temperature biases verified against surface observations in area 2, the NH, the tropics and the SH. The solid line is the operational value and the dashed line is the trial value.

Figure 4.30 The 1.5m temperature biases verified against analyses in area 2, the NH, the tropics and the SH. The solid line is the operational value and the dashed line is the trial value.

Figure 4.31 The 10m wind speed biases verified against surface observations in area 2, the NH, the tropics and the SH. The solid line is the operational value and the dashed line is the trial value.

Figure 4.32 The 10m wind speed biases verified against analyses in area 2, the NH, the tropics and the SH. The solid line is the operational value and the dashed line is the trial value.

Figure 4.33 The percentage change in the RMS height errors verified against upper air reports at T+00 and T+36 in the full LAM area and UK & Iceland. The dotted vertical lines are at $\pm 1\%$, which is considered the limit of practical significance.

Figure 4.34 The percentage change in the RMS temperature errors verified against upper air reports at T+00 and T+36 in the full LAM area and UK & Iceland. The dotted vertical lines are at $\pm 1\%$, which is considered the limit of practical significance.

Figure 4.35 The percentage change in the RMS VWE verified against upper air reports at T+00 and T+36 in the full LAM area and UK & Iceland. The dotted vertical lines are at $\pm 1\%$, which is considered the limit of practical significance.

Figure 4.36 The percentage change in the RMS 10m VWE and 1.5m temperature errors verified against surface observations in the full LAM area and UK & Iceland. The dotted vertical lines are at $\pm 1\%$, which is considered the limit of practical significance.

Figure 4.37 The percentage change in the RMS height errors verified against analyses at T+12, T+24 and T+36 in the full LAM area. The dotted vertical lines are at $\pm 1\%$, which is considered the limit of practical significance.

Figure 4.38 The percentage change in the RMS temperature errors verified against analyses at T+12, T+24 and T+36 in the full LAM area. The dotted vertical lines are at $\pm 1\%$, which is considered the limit of practical significance.

Figure 4.39 The percentage change in the RMS VWE verified against analyses at T+24 and T+36 in the full LAM area and UK & Iceland. The dotted vertical lines are at $\pm 1\%$, which is considered the limit of practical significance.

Figure 4.40 The percentage change in the RMS PMSL errors, 1.5m temperature errors and 10m VWE verified against analyses in the full LAM area. The dotted vertical lines are at $\pm 1\%$, which is considered the limit of practical significance.

Figure 4.41 The RMS and mean height errors at T+00 in UK & Iceland and the full LAM area for: operational global model (smoothed, solid line); high resolution global model (smoothed, dashed line); operational LAM (unsmoothed, dotted line); high resolution global model (unsmoothed, dot-dahsed line).

PARALLEL SUITE EXPERIMENT No.40

Tropical Cyclone Forecast Track Verification

1. Sponsor

Clive Wilson, NWP Division.

2. Description of Experiment

Increased horizontal resolution (432x325) and 2 hours data cut-off for main runs

3. Duration and Forecast Specification

The total period of the experiment was from 25.05.96 to 28.06.96

PS forecasts were run out to T+36 every 12 hours. Verification of T+0 and T+24 tropical storm locations was made.

4. Tropical Cyclone Forecast Verification

a) Differences in samples

None

b) Verification Statistics

Total number of storms which were active during the period : **5**

Homogeneous samples were used in the statistical comparison

Forecast Error comparison for whole globe

	T+0	T+24
No. verified	27	17
Operational DPE	59	183
Parallel Suite DPE	98	151
% increase	+66.1	-17.5

No. verified : The number of forecasts verified for each forecast time
DPE : Direct Positional Error in kilometres
% increase : Percentage increase in PS forecast error compared to OS

The overall percentage increase in PS analysis/forecast error : +33.8%

Forecast Error comparison for North-East Pacific Basin

	T+0	T+24
No. verified	10	8
Operational DPE	76	199
Parallel Suite DPE	62	109
% increase	-18.4	-45.2

The overall percentage increase in PS analysis/forecast error : -30.3%

Forecast Error comparison for North Atlantic Basin

	T+0	T+24
No. verified	3	1
Operational DPE	45	72
Parallel Suite DPE	36	71
% increase	-20.0	-1.3

The overall percentage increase in PS analysis/forecast error : -15.3%

Forecast Error comparison for North Indian Basin

	T+0	T+24
No. verified	14	8
Operational DPE	50	181
Parallel Suite DPE	137	202
% increase	+174.0	+11.6

The overall percentage increase in PS analysis/forecast error : +114.9%

5. Comments

The results from this experiment indicate clearly the impact of increasing the global model resolution and reducing the main run cut-off on TC forecasts. In the North-East Pacific basin the earlier cut-off time has no effect on bogus data used to intialise the storms since the advisories used are valid at 03Z, 09Z etc. and are received well before the earlier cut-off. Hence, the only change in the parallel run for these storms is the model resolution. Analysis errors were reduced by 18.4% and T+24 errors by a massive 45.2% clearly indicating the benefit of the higher resolution. The sample size for the North Atlantic was very small, but the 3 analyses verified all had smaller errors in the parallel suite run.

Statistics for the North Indian basin show a very different story as parallel run analysis errors were 174% higher and T+24 errors 11.6% higher. This is because advisories used for bogussing in these areas are valid at the main forecast hours and are often not received before the 2 hour cut-off for this experiment. Hence, the benefit of higher model resolution is lost in this case due to poorer initialisation of the storms.

Overall, these results indicate that higher model resolution will have a major positive impact on TC analyses and forecasts at least up to T+24, but loss of bogus data due to the earlier cut-off time is an issue that must be addressed before it is adopted operationally.

Details of the formulation of the UKMO TC verification Scheme can be found in *nwp Gazette* Vol.1, No.2, December 1994.

Julian Heming, FS9

PARALLEL SUITE EXPERIMENT No.41

Tropical Cyclone Forecast Track Verification

1. Sponsor

Clive Wilson, NWP Division.

2. Description of Experiment

Increased horizontal resolution (432x325) and 2 hours data cut-off for main runs.

3. Duration and Forecast Specification

The total period of the experiment was from 05.07.96 to 14.07.96

PS forecasts were run out to T+72 every 24 hours at 12Z.

4. Tropical Cyclone Forecast Verification

a) Differences in samples

The OS run DT 12Z 05.07.96 dissipated TC Bertha by T+24; the corresponding PS run did not.
The OS run DT 12Z 08.07.96 made TC Dan extra-tropical by T+72; the corresponding PS run made it extra-tropical by T+96.
The OS run DT 12Z 10.07.96 made TC Dan extra-tropical by T+24; the corresponding PS run made it extra-tropical by T+48.
The OS run DT 12Z 10.07.96 made TC Bertha extra-tropical by T+72; the corresponding PS run made it extra-tropical by T+96.

b) Verification Statistics

Total number of storms which were active during the period : **2**

Homogeneous samples were used in the statistical comparison

Forecast Error comparison for whole globe

	T+0	T+24	T+48	T+72
No. verified	14	10	8	5
Operational DPE	42	104	207	399
Parallel Suite DPE	89	105	118	194
% increase	+111.9	+1.0	-43.0	-51.4

No. verified : The number of forecasts verified for each forecast time
DPE : Direct Positional Error in kilometres
% increase : Percentage increase in PS forecast error compared to OS

The overall percentage increase in PS analysis/forecast error : +26.4%
The overall percentage increase in PS forecast error : -25.7%

Forecast Error comparison for North-West Pacific Basin (Typhoon Dan)

	T+0	T+24	T+48	T+72
No. verified	5	3	2	1
Operational DPE	58	165	204	430
Parallel Suite DPE	161	173	166	346
% increase	+177.6	+4.8	-18.6	-19.5

The overall percentage increase in PS analysis/forecast error : +76.9%
The overall percentage increase in PS forecast error : -7.0%

Forecast Error comparison for North Atlantic Basin (Hurricane Bertha)

	T+0	T+24	T+48	T+72
No. verified	9	7	6	4
Operational DPE	34	77	208	391
Parallel Suite DPE	49	76	102	157
% increase	+44.1	-1.3	-51.0	-59.8

The overall percentage increase in PS analysis/forecast error : -6.1%
The overall percentage increase in PS forecast error : -32.6%

5. Comments

PS analyses of Hurricane Bertha were slightly worse than OS analyses. Since the bogussing would have been identical in both runs this difference can only be attributed to the impact of real observations received between the PS cut-off time of 1400 and the OS cut-off of 1505. Despite the slightly poorer analyses, all forecasts of Hurricane Bertha were improved by the higher resolution run, most notably at T+48 and T+72 where forecast errors were more than halved. The two forecasts with the largest differences were from data times 12Z 09.07.96 and 10.07.96. The OS forecasts turned the storm too quickly and engaged it with a passing trough causing the low centre to become elongated. The PS forecasts all retained a much deeper centre on the storm and in these two cases maintained the near symmetry of the storm, correctly steering it on a track further to the west towards land. Attached charts show OP and PS forecast tracks.

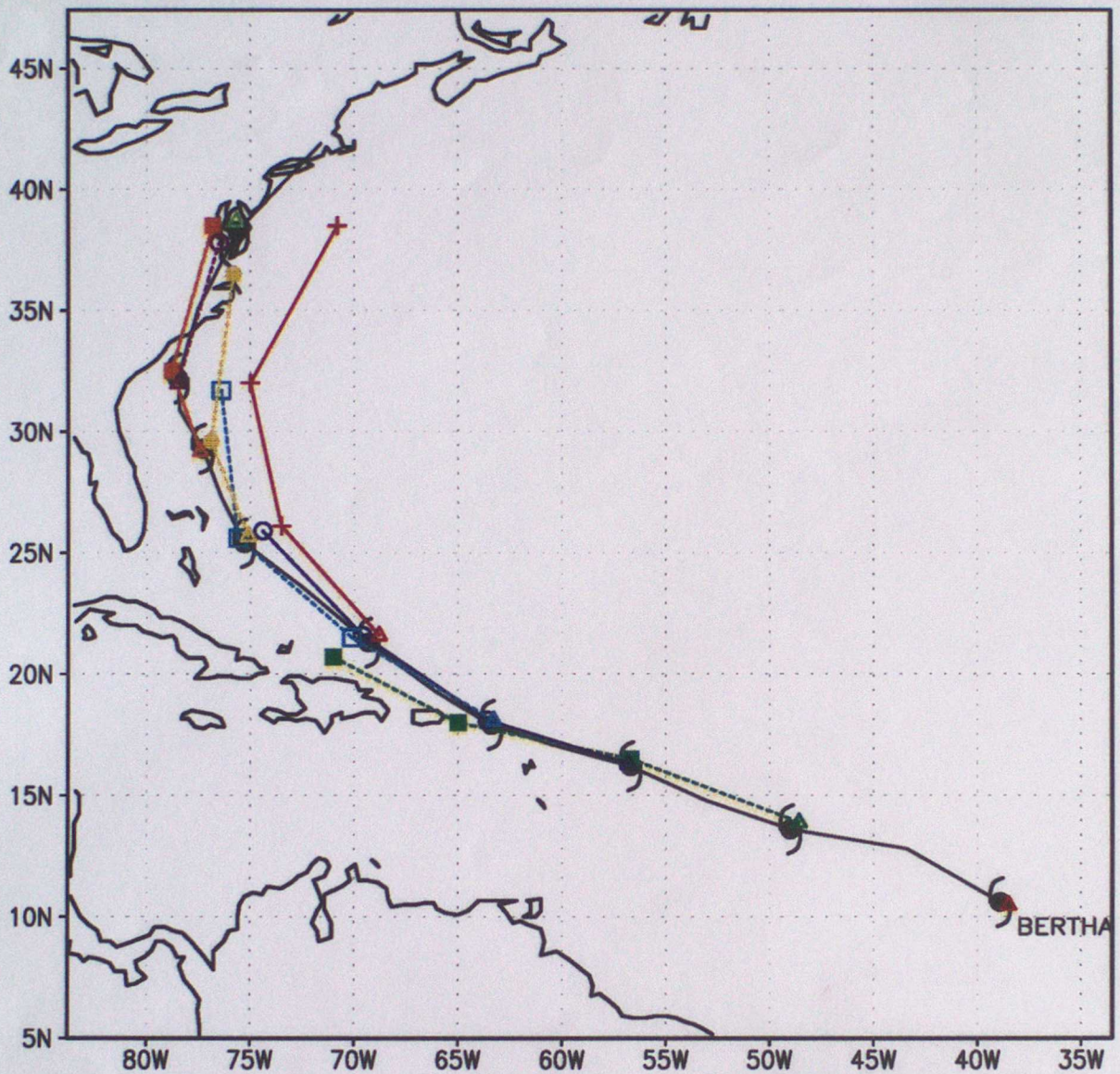
Typhoon Dan's analyses were much poorer in the PS run due to lack of bogussing at 12Z resulting from the earlier cut-off time. However, forecasts at T+48 and T+72 were better than the OS although sample sizes were small. In this experiment only the 12Z bogussing would have missed the cut-off time; 00Z, 06Z and 18Z bogussing would have still been used in the PS run.

In all cases the centres of storms were much deeper (over 10mb in some cases) and relative vorticity much stronger (more than doubled in some cases) in the PS run. This is a major improvement since one of the weaknesses of the current model is that it tends to dissipate TCs too early in the forecast. The higher resolution model will retain the storms much longer due to their deeper centres.

Details of the formulation of the UKMO TC verification Scheme can be found in *nwp Gazette* Vol.1, No.2, December 1994.

Julian Heming, FS9

UK METEOROLOGICAL OFFICE GLOBAL MODEL FORECAST TRACKS of HURRICANE BERTHA



UK 960705 UK 960706 UK 960707 UK 960708 UK 960709 UK 960710
UK 960711 UK 960712 UK 960713

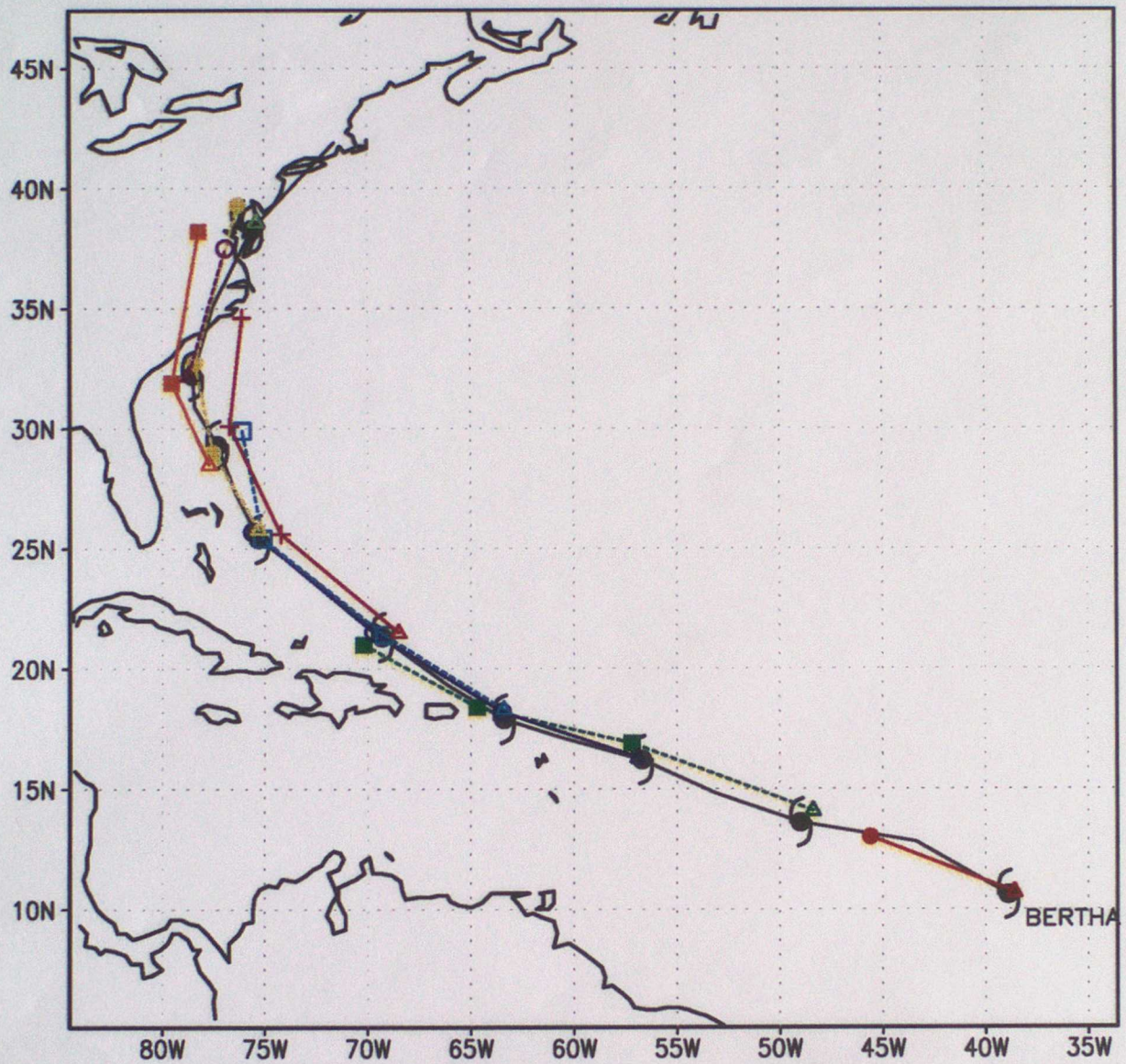
KEY to FORECAST TRACKS
(Triangles denote analysed positions)

24 HOURLY REAL TIME OBSERVED POSITIONS

DATE/TIME OF FIRST SYMBOL 12Z 05 JULY 1996

TEST TRACKS

FORECAST TRACKS of HURRICANE BERTHA



TE 960705 TE 960706 TE 960707 TE 960708 TE 960709 TE 960710
TE 960711 TE 960712 TE 960713

KEY to FORECAST TRACKS

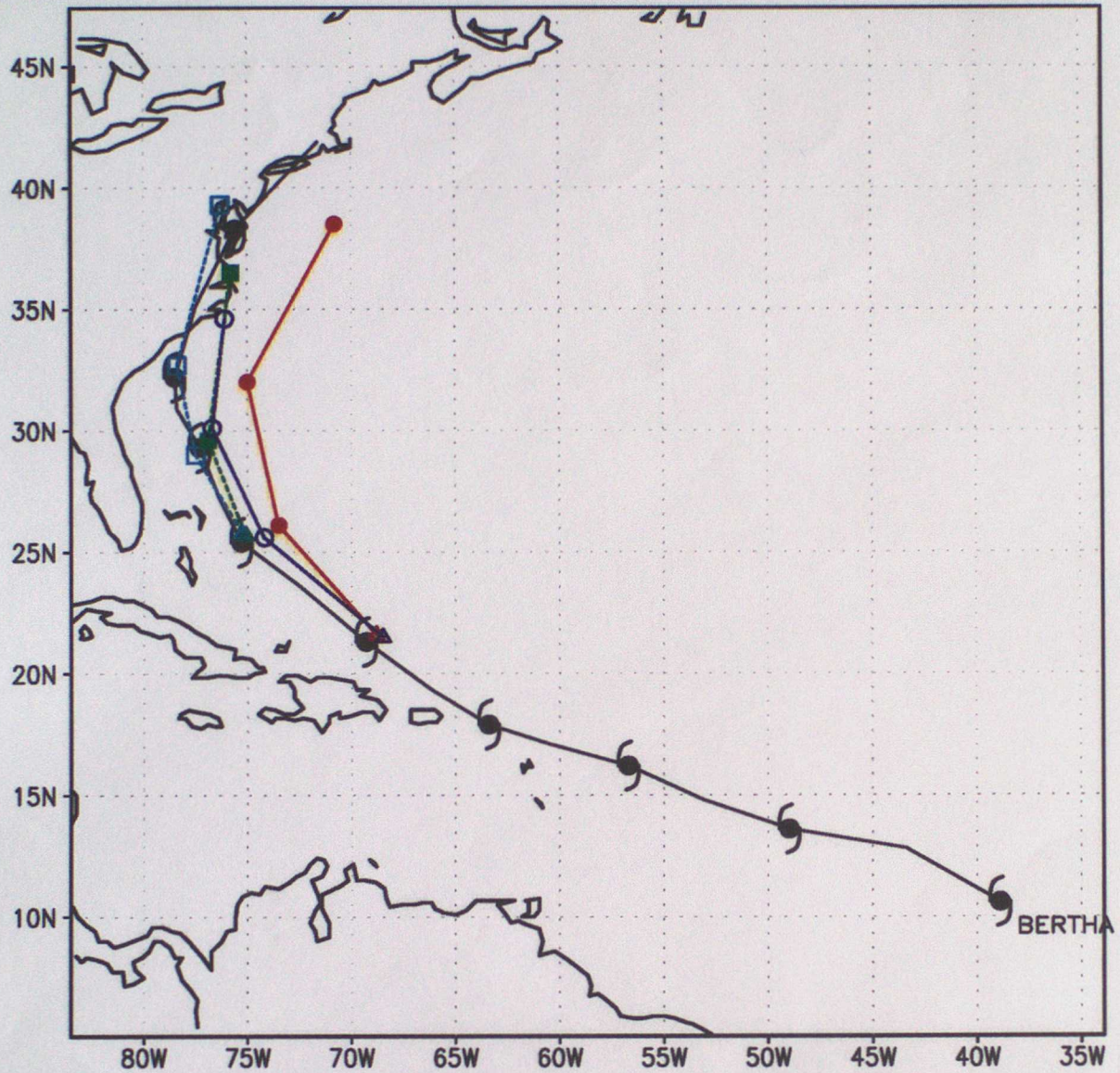
(Triangles denote analysed positions)

24 HOURLY REAL TIME OBSERVED POSITIONS

DATE/TIME OF FIRST SYMBOL 12Z 05 JULY 1996

UKMO GLOBAL MODEL and TEST

FORECAST TRACKS of HURRICANE BERTHA



UK 960709 UK 960710 TE 960709 TE 960710

KEY to FORECAST TRACKS

(Triangles denote analysed positions)

24 HOURLY REAL TIME OBSERVED POSITIONS

DATE/TIME OF FIRST SYMBOL 12Z 05 JULY 1996

APPENDIX B: COMPARISON OF VERIFICATION OF HIGH RESOLUTION TRIAL AND OPERATIONAL GLOBAL CONTROL

All table show percentage change in RMS errors. A negative value indicates that the trial has smaller errors.

TABLE B.1

Verification against sondes
Period= 06/06/96-14/07/96

Height
AREA 2

	T+00	T+12	T+24	T+36
850.0	-0.1	-1.2	-3.3	-2.8
700.0	0.5	-0.4	-2.1	-2.2
500.0	0.1	-0.8	-2.1	-2.9
300.0	-0.3	-3.4	-3.5	-3.5
250.0	-0.8	-3.7	-4.9	-4.5
200.0	-1.4	-2.6	-3.9	-5.0
100.0	-1.6	-1.2	-2.3	-3.4
50.0	-0.4	-2.5	-3.7	-6.0
Mean	-0.5	-2.0	-3.2	-3.8

NH

	T+00	T+12	T+24	T+36
850.0	0.0	-2.1	-2.9	-3.0
700.0	0.3	-1.2	-1.7	-2.6
500.0	0.6	-0.5	-1.3	-1.6
300.0	0.8	-1.3	-2.6	-1.6
250.0	0.7	-1.6	-3.6	-2.4
200.0	0.5	-1.1	-3.7	-3.0
100.0	0.8	-1.2	-2.9	-2.2
50.0	3.9	0.6	-0.2	-0.8
Mean	1.0	-1.1	-2.4	-2.2

TROPICS

	T+00	T+12	T+24	T+36
850.0	-1.0	-1.1	-0.9	0.1
700.0	0.2	-0.9	-0.2	0.9
500.0	0.8	-0.4	0.4	0.8
300.0	1.9	1.2	-0.2	0.1
250.0	1.6	1.0	-0.2	0.3
200.0	1.4	0.8	-0.6	0.3
100.0	1.2	-0.4	-1.1	-1.0
50.0	1.7	0.1	1.2	0.2
Mean	1.0	0.0	-0.2	0.2

SH

	T+00	T+12	T+24	T+36
850.0	4.9	14.7	8.9	13.5
700.0	3.9	11.7	9.9	14.6
500.0	3.0	10.8	8.6	12.7
300.0	1.5	5.2	4.9	10.6
250.0	0.0	2.7	3.8	9.8
200.0	-1.4	0.7	2.7	8.9
100.0	-0.6	0.2	2.2	8.8
50.0	1.7	0.2	1.3	2.5
Mean	1.6	5.8	5.3	10.2

TABLE B.2

Verification against sondes
Period= 06/06/96-14/07/96

Temperature
AREA 2

	T+00	T+12	T+24	T+36
850.0	-0.5	-1.6	-2.6	-2.4
700.0	0.0	-1.9	-1.9	-0.8
500.0	-0.4	-2.1	-2.2	-2.4
300.0	-0.6	-3.3	-5.3	-6.4
250.0	-0.2	-2.8	-2.8	-2.2
200.0	-1.2	-2.7	-2.2	-1.1
100.0	1.5	-0.9	-0.4	-2.6
50.0	-0.1	0.7	3.6	5.6
Mean	-0.2	-1.8	-1.7	-1.5

NH

	T+00	T+12	T+24	T+36
850.0	2.2	-2.1	-3.5	-3.2
700.0	0.8	-0.8	-1.5	-1.4
500.0	1.4	-0.9	-1.5	-2.2
300.0	1.0	-2.2	-4.3	-4.7
250.0	0.6	-2.6	-2.8	-4.1
200.0	0.6	-1.3	-2.0	-2.0
100.0	2.5	0.7	1.3	0.6
50.0	10.0	4.7	5.9	5.6
Mean	2.4	-0.6	-1.1	-1.4

TROPICS

	T+00	T+12	T+24	T+36
850.0	3.4	0.0	-1.8	-1.4
700.0	6.2	0.0	-1.1	0.0
500.0	6.8	2.4	1.7	0.0
300.0	5.8	0.0	-2.2	0.0
250.0	5.1	0.8	-0.3	0.7
200.0	7.7	0.8	-1.7	-0.7
100.0	0.6	1.6	0.8	2.2
50.0	2.4	1.5	1.7	0.4
Mean	4.8	0.9	-0.4	0.2

SH

	T+00	T+12	T+24	T+36
850.0	4.9	6.1	5.4	5.6
700.0	3.7	1.2	2.9	6.4
500.0	-0.8	-2.9	-0.4	4.6
300.0	1.2	1.8	-0.3	2.8
250.0	3.7	6.1	2.2	4.5
200.0	2.2	3.4	2.8	5.3
100.0	1.9	1.1	2.6	3.0
50.0	0.1	0.5	-0.7	-0.4
Mean	2.1	2.2	1.8	4.0

TABLE B.3

Verification against sondes
Period= 06/06/96-14/07/96

Relative humidity
AREA 2

	T+00	T+12	T+24	T+36
850.0	1.9	-2.4	-3.2	-4.2
700.0	1.6	-0.7	-0.4	-0.3
500.0	3.6	-2.6	-2.4	-2.7
Mean	2.4	-1.9	-2.0	-2.4

NH

	T+00	T+12	T+24	T+36
850.0	3.8	-1.5	-2.5	-2.9
700.0	3.5	-0.7	-0.6	-0.9
500.0	5.6	-1.8	-1.4	-1.7
Mean	4.3	-1.3	-1.5	-1.8

TROPICS

	T+00	T+12	T+24	T+36
850.0	14.7	1.6	1.7	1.7
700.0	21.5	2.9	2.4	2.1
500.0	22.4	3.8	2.4	2.1
Mean	19.5	2.8	2.2	2.0

SH

	T+00	T+12	T+24	T+36
850.0	7.3	-0.2	1.2	1.0
700.0	9.1	0.9	0.0	-1.0
500.0	19.9	5.9	3.5	-0.1
Mean	12.1	2.2	1.6	-0.0

TABLE B.4

Verification against sondes
Period= 06/06/96-14/07/96

Wind
AREA 2

	T+00	T+12	T+24	T+36
850.0	1.2	-1.8	-2.5	-0.9
700.0	1.4	-1.6	-1.9	-1.9
300.0	-0.2	-3.2	-3.2	-1.0
250.0	-0.7	-2.2	-2.4	-0.7
200.0	0.1	-0.4	0.2	1.2
100.0	2.6	2.5	2.5	2.6
Mean	0.7	-1.1	-1.2	-0.1

NH

	T+00	T+12	T+24	T+36
850.0	2.8	-0.8	-1.4	-0.3
700.0	3.3	-0.8	-1.1	-0.3
300.0	2.4	-1.3	-1.4	-0.9
250.0	1.9	-0.5	-1.0	-0.2
200.0	2.6	0.8	-0.1	0.7
100.0	7.2	2.1	1.6	2.4
Mean	3.4	-0.1	-0.6	0.2

TROPICS

	T+00	T+12	T+24	T+36
850.0	8.4	2.0	0.6	0.0
700.0	14.7	4.1	2.8	2.5
300.0	16.4	4.0	3.0	2.1
250.0	16.0	2.0	3.1	2.3
200.0	17.8	2.8	2.1	0.8
100.0	11.3	3.5	2.8	3.3
Mean	14.1	3.1	2.4	1.8

SH

	T+00	T+12	T+24	T+36
850.0	10.2	4.5	5.8	9.0
700.0	8.4	2.9	5.6	8.3
300.0	13.3	8.9	6.9	9.5
250.0	10.3	7.1	6.0	8.2
200.0	7.5	5.0	5.3	6.5
100.0	5.2	2.5	2.3	2.8
Mean	9.2	5.2	5.3	7.4

TABLE B.5

Verification against surface obs
Period= 06/06/96-14/07/96

PMSL
AREA 2

T+00	T+12	T+24	T+36
0.1	2.6	-0.5	-1.2

NH

T+00	T+12	T+24	T+36
0.6	0.0	-2.7	-2.4

TROPICS

T+00	T+12	T+24	T+36
1.1	-2.0	-2.2	-2.0

SH

T+00	T+12	T+24	T+36
2.4	4.2	3.1	6.4

1.5m Temperature
AREA 2

T+00	T+12	T+24	T+36
-2.4	-1.1	-0.7	0.0

NH

T+00	T+12	T+24	T+36
-1.7	-1.4	-1.1	-1.0

TROPICS

T+00	T+12	T+24	T+36
-1.3	-0.8	-1.5	-1.2

SH

T+00	T+12	T+24	T+36
-0.3	1.0	1.0	2.9

10m Wind
AREA 2

T+00	T+12	T+24	T+36
-0.6	-1.2	-1.4	-1.7

NH

T+00	T+12	T+24	T+36
-0.8	-1.4	-1.7	-1.9

TROPICS

T+00	T+12	T+24	T+36
0.9	-1.1	-1.4	-1.2

SH

T+00	T+12	T+24	T+36
0.5	0.4	0.9	2.8

TABLE B.6

Verification against analyses
Period= 06/06/96-14/07/96

Height
AREA 2

	T+12	T+24	T+36
850.0	-6.5	0.0	-0.5
700.0	-2.8	2.2	3.3
500.0	-2.5	0.6	1.9
300.0	-3.1	-1.6	-0.5
250.0	-2.0	-2.6	-1.2
200.0	0.1	-1.3	-1.3
100.0	6.0	4.1	-2.8
50.0	4.3	8.0	-2.1
Mean	-0.8	1.2	-0.4

NH

	T+12	T+24	T+36
850.0	-4.0	-1.6	-2.2
700.0	-1.9	-0.3	-0.3
500.0	1.2	0.5	0.8
300.0	2.4	-0.5	1.0
250.0	3.1	-2.0	0.6
200.0	4.5	-2.5	0.3
100.0	4.6	-3.0	-1.2
50.0	-1.6	-1.6	-0.4
Mean	1.0	-1.4	-0.2

TROPICS

	T+12	T+24	T+36
850.0	-4.0	-0.1	0.3
700.0	-3.5	-0.7	-0.2
500.0	1.3	2.2	1.3
300.0	-0.3	3.3	2.7
250.0	-2.2	1.9	1.3
200.0	-2.5	1.0	0.6
100.0	-1.1	-4.4	-0.1
50.0	2.3	-4.1	-3.5
Mean	-1.3	-0.1	0.3

SH

	T+12	T+24	T+36
850.0	3.2	2.6	5.0
700.0	4.6	4.1	5.6
500.0	4.4	5.1	6.0
300.0	4.8	4.1	5.0
250.0	4.9	3.1	4.0
200.0	3.8	1.9	3.0
100.0	3.7	0.4	5.5
50.0	6.3	0.6	6.7
Mean	4.5	2.7	5.1

TABLE B.7

Verification against analyses
Period= 06/06/96-14/07/96

Temperature
AREA 2

	T+12	T+24	T+36
850.0	-1.4	-2.3	-0.8
700.0	-1.6	-2.2	1.0
500.0	-4.9	-1.4	-1.9
300.0	1.3	-3.6	-3.5
250.0	0.0	-2.5	-1.2
200.0	2.7	-0.8	0.7
100.0	2.5	7.3	3.0
50.0	-9.0	17.5	2.9
Mean	-1.3	1.5	0.0

NH

	T+12	T+24	T+36
850.0	4.1	-1.2	-0.7
700.0	3.3	0.3	1.0
500.0	3.6	2.1	1.0
300.0	4.2	-1.1	-0.8
250.0	2.6	-1.0	-2.1
200.0	5.9	1.0	0.7
100.0	4.2	6.4	6.5
50.0	-3.0	6.2	6.4
Mean	3.1	1.6	1.5

TROPICS

	T+12	T+24	T+36
850.0	0.0	-1.6	-2.6
700.0	2.1	2.7	3.6
500.0	-2.0	1.3	1.1
300.0	5.7	1.2	1.1
250.0	6.1	1.1	0.0
200.0	4.2	-1.4	0.0
100.0	8.7	3.1	2.4
50.0	7.8	3.3	1.3
Mean	4.1	1.2	0.9

SH

	T+12	T+24	T+36
850.0	2.2	0.8	2.2
700.0	2.1	2.0	3.1
500.0	3.5	5.3	5.5
300.0	7.4	5.1	6.0
250.0	6.3	5.6	6.7
200.0	6.6	4.9	6.7
100.0	8.3	5.0	6.9
50.0	13.7	7.4	5.5
Mean	6.3	4.5	5.3

TABLE B.8

Verification against analyses
Period= 06/06/96-14/07/96

Relative humidity
AREA 2

	T+12	T+24	T+36
950.0	-1.2	-0.3	0.7
850.0	-3.2	-0.9	0.2
700.0	0.7	1.6	4.1
500.0	-0.3	0.9	3.4
Mean	-1.0	0.3	2.1

NH

	T+12	T+24	T+36
950.0	0.0	-0.6	0.5
850.0	0.5	0.3	1.6
700.0	2.2	3.8	5.6
500.0	0.2	2.6	4.2
Mean	0.7	1.5	3.0

TROPICS

	T+12	T+24	T+36
950.0	1.1	-1.3	1.3
850.0	4.6	1.8	2.5
700.0	5.3	2.8	3.0
500.0	5.2	5.4	5.5
Mean	4.1	2.2	3.1

SH

	T+12	T+24	T+36
950.0	0.6	0.4	1.2
850.0	7.2	6.8	6.3
700.0	7.3	7.6	5.8
500.0	10.8	8.4	6.0
Mean	6.5	5.8	4.8

TABLE B.9

Verification against analyses
Period= 06/06/96-14/07/96

Wind
AREA 2

	T+12	T+24	T+36
850.0	-3.2	-1.4	1.2
700.0	-1.0	0.2	3.1
300.0	1.3	0.2	2.3
250.0	0.5	-0.4	0.5
200.0	1.6	0.6	0.5
100.0	5.9	5.8	7.3
Mean	0.9	0.8	2.5

NH

	T+12	T+24	T+36
850.0	-1.2	-0.6	2.1
700.0	1.6	0.9	4.0
300.0	4.0	2.8	3.9
250.0	4.4	1.8	2.5
200.0	6.2	2.1	3.5
100.0	7.3	5.5	6.0
Mean	3.7	2.1	3.7

TROPICS

	T+12	T+24	T+36
850.0	1.8	0.4	1.3
700.0	6.0	2.3	5.1
300.0	9.9	6.8	7.4
250.0	6.0	4.4	6.9
200.0	7.5	4.6	7.1
100.0	11.2	6.0	7.9
Mean	7.1	4.1	6.0

SH

	T+12	T+24	T+36
850.0	2.6	6.9	9.7
700.0	5.4	9.6	12.7
300.0	9.8	9.5	10.9
250.0	7.8	7.2	8.7
200.0	6.7	5.8	7.1
100.0	7.3	6.4	8.6
Mean	6.6	7.6	9.6

TABLE B.10

Verification against analyses
Period= 06/06/96-14/07/96

PMSL
AREA 2

T+12	T+24	T+36
-6.5	-1.7	-2.1

NH

T+12	T+24	T+36
-3.7	-2.4	-2.6

TROPICS

T+12	T+24	T+36
-4.2	0.7	0.9

SH

T+12	T+24	T+36
2.1	1.5	4.5

10m Wind
AREA 2

T+12	T+24	T+36
-3.1	-1.3	0.1

NH

T+12	T+24	T+36
-1.7	-1.1	0.7

TROPICS

T+12	T+24	T+36
1.5	0.6	2.0

SH

T+12	T+24	T+36
3.0	6.6	9.3

1.5m Temperature
AREA 2

T+12	T+24	T+36
-7.2	-5.4	-2.4

NH

T+12	T+24	T+36
3.1	-2.3	-0.8

TROPICS

T+12	T+24	T+36
0.0	-1.6	-4.1

SH

T+12	T+24	T+36
-2.4	-1.4	-1.1

TABLE B.11

Verification against AIREP's
Period= 06/06/96-14/07/96

Temperature

AREA 2

	T+00	T+12	T+24	T+36
300.0	-1.2	-4.1	-2.7	-4.8
250.0	-0.2	-1.5	-2.2	-2.5
200.0	-0.3	1.0	-0.2	-0.4
Mean	-0.6	-1.5	-1.7	-2.6

NH

	T+00	T+12	T+24	T+36
300.0	-1.2	-3.3	-2.3	-4.2
250.0	-0.2	-1.6	-1.9	-3.2
200.0	-0.2	0.0	-1.5	-1.4
Mean	-0.5	-1.6	-1.9	-2.9

TROPICS

	T+00	T+12	T+24	T+36
300.0	-0.7	-1.2	-1.8	1.1
250.0	-2.8	-1.4	0.2	-0.6
200.0	-3.0	0.0	1.4	3.1
Mean	-2.2	-0.9	-0.1	1.2

SH

	T+00	T+12	T+24	T+36
300.0	1.3	2.2	5.4	1.5
250.0	-1.4	5.2	3.3	5.8
200.0	-1.2	3.1	2.5	11.7
Mean	-0.4	3.5	3.7	6.3

TABLE B.12

Verification against AIREP's
Period= 06/06/96-14/07/96

Wind

AREA 2

	T+ 00	T+ 12	T+ 24	T+ 36
250.0	0.8	-1.4	-3.2	-7.2
200.0	0.9	0.3	-2.1	-2.6
Mean	0.9	-0.6	-2.7	-4.9

NH

	T+ 00	T+ 12	T+ 24	T+ 36
250.0	1.3	-0.7	-2.1	-3.1
200.0	1.9	-0.3	-2.3	-2.6
Mean	1.6	-0.5	-2.2	-2.9

TROPICS

	T+ 00	T+ 12	T+ 24	T+ 36
250.0	7.4	3.7	2.9	1.3
200.0	3.4	-5.4	-1.9	-5.0
Mean	5.4	-0.9	0.5	-1.9

SH

	T+ 00	T+ 12	T+ 24	T+ 36
250.0	0.2	-0.8	1.4	3.7
200.0	-0.8	0.6	1.7	1.6
Mean	-0.3	-0.1	1.6	2.7

TABLE B.13

Verification against AMDARs
Period= 06/06/96-14/07/96

Temperature
AREA 2

	T+00	T+12	T+24	T+36
700.0	-0.9	-0.8	-0.2	-0.7
500.0	0.3	-1.1	-1.1	-2.1
300.0	-0.8	-4.1	-3.1	-5.0
250.0	-2.0	-3.1	-5.1	-6.6
200.0	-0.4	-2.0	-1.5	-3.8
100.0	-0.1	0.0	0.2	0.1
Mean	-0.7	-1.9	-1.8	-3.0

NH

	T+00	T+12	T+24	T+36
700.0	0.4	0.0	1.4	-0.5
500.0	-0.2	-0.2	0.0	-0.5
300.0	-0.4	-1.0	-1.6	-2.7
250.0	-0.8	-2.0	-2.7	-4.1
200.0	-0.5	-0.5	0.3	-0.8
100.0	7.5	6.8	7.8	7.2
Mean	1.0	0.5	0.9	-0.2

TROPICS

	T+00	T+12	T+24	T+36
700.0	-4.9	-3.8	-6.9	-4.8
500.0	-0.2	-1.6	-1.8	-1.6
300.0	2.6	4.6	1.8	2.8
250.0	1.9	-0.5	0.1	-0.4
200.0	1.9	-1.3	-1.5	-0.4
100.0				
Mean	0.3	-0.5	-1.7	-0.9

SH

	T+00	T+12	T+24	T+36
700.0	1.0	-1.7	-0.2	5.2
500.0	1.0	3.5	3.0	4.6
300.0	1.4	2.7	6.9	7.0
250.0	0.2	5.6	5.4	10.6
200.0	-0.2	1.6	3.3	7.0
100.0				
Mean	0.7	2.3	3.7	6.9

TABLE B.14

Verification against AMDARs
Period= 06/06/96-14/07/96

Wind

AREA 2

	T+ 00	T+ 12	T+ 24	T+ 36
700.0	0.3	-3.4	-2.5	-5.1
300.0	1.7	-3.6	-4.5	-4.2
250.0	1.2	-1.2	-1.9	-4.8
200.0	1.2	0.9	1.0	-1.2
Mean	1.1	-1.8	-2.0	-3.8

NH

	T+ 00	T+ 12	T+ 24	T+ 36
700.0	1.0	-0.5	-0.4	-0.8
300.0	5.3	3.6	0.1	1.9
250.0	1.5	0.5	0.1	-1.9
200.0	1.0	0.5	1.4	-0.1
Mean	2.2	1.0	0.3	-0.2

TROPICS

	T+ 00	T+ 12	T+ 24	T+ 36
700.0	6.8	4.1	-1.3	3.0
300.0	8.6	7.7	4.2	8.4
250.0	4.2	-1.6	-0.7	1.6
200.0	2.7	-1.0	0.8	-0.1
Mean	5.6	2.3	0.8	3.2

SH

	T+ 00	T+ 12	T+ 24	T+ 36
700.0	1.4	3.2	3.2	10.3
300.0	1.7	3.2	4.5	8.5
250.0	1.3	3.2	3.0	7.2
200.0	2.0	5.1	2.7	4.5
Mean	1.6	3.7	3.4	7.6

APPENDIX C: COMPARISON OF VERIFICATION OF HIGH RESOLUTION TRIAL AND OPERATIONAL LIMITED AREA CONTROL

All table show percentage change in RMS errors. A negative value indicates that the trial has smaller errors.

TABLE C.1

Verification against sondes
Period= 01/06/96-14/07/96

Height
LAM area

	T+00	T+12	T+24	T+36
850.0	-0.6	-3.4	-6.2	-6.5
700.0	1.8	-2.8	-5.0	-8.4
500.0	2.3	-2.4	-5.4	-8.8
300.0	2.2	-2.6	-5.3	-10.2
250.0	2.7	-2.7	-5.0	-10.7
200.0	2.9	-2.5	-5.1	-10.7
100.0	3.5	-4.3	-4.0	-9.5
Mean	2.1	-3.0	-5.1	-9.3

UK & Iceland

	T+00	T+12	T+24	T+36
850.0	3.7	-1.5	-5.0	-10.4
700.0	5.8	1.3	0.0	-10.7
500.0	3.8	1.2	1.0	-10.4
300.0	3.5	-3.5	-1.3	-10.2
250.0	4.0	-5.5	-5.4	-10.8
200.0	3.5	-4.3	-3.9	-13.1
100.0	0.2	-2.9	-2.3	-15.1
Mean	3.5	-2.2	-2.4	-11.5

TABLE C.2

Verification against sondes
Period= 01/06/96-14/07/96

Temperature
LAM area

	T+ 00	T+ 12	T+ 24	T+ 36
850.0	-0.3	-3.8	-2.9	-3.6
700.0	-1.3	-1.8	-4.0	-4.3
500.0	1.9	-1.0	-3.4	-7.3
300.0	-6.6	-6.5	-7.7	-9.1
250.0	-8.0	-6.7	-8.6	-9.4
200.0	1.2	-2.6	-4.0	-5.6
100.0	7.6	0.8	2.2	0.0
Mean	-0.8	-3.1	-4.1	-5.6

UK & Iceland

	T+ 00	T+ 12	T+ 24	T+ 36
850.0	0.6	-2.6	-1.9	0.0
700.0	-1.7	-2.1	-0.3	-3.1
500.0	4.2	3.6	1.4	-7.6
300.0	-6.6	-7.5	-9.6	-6.2
250.0	-8.0	-4.9	-2.5	-10.1
200.0	-2.5	-4.9	-3.6	-1.6
100.0	-1.6	-6.9	-4.5	-8.8
Mean	-2.2	-3.6	-3.0	-5.3

TABLE C.3

Verification against sondes
Period= 01/06/96-14/07/96

Relative humidity
LAM area

	T+00	T+12	T+24	T+36
850.0	3.0	-3.4	-1.9	-2.6
700.0	8.0	-1.1	-1.9	-2.2
500.0	12.6	-1.7	-2.7	-3.0
Mean	7.9	-2.1	-2.2	-2.6

UK & Iceland

	T+00	T+12	T+24	T+36
850.0	4.1	-0.9	0.5	0.0
700.0	5.4	-1.2	0.6	0.9
500.0	10.9	-0.3	0.8	0.2
Mean	6.8	-0.8	0.6	0.4

TABLE C.4

Verification against sondes
Period= 01/06/96-14/07/96

Wind
LAM area

	T+00	T+12	T+24	T+36
850.0	2.3	-2.4	-3.8	-5.5
700.0	0.5	-2.3	-3.0	-5.3
500.0	-1.7	-3.9	-3.0	-6.2
300.0	-0.6	-4.8	-5.7	-7.9
250.0	1.5	-3.2	-6.2	-7.8
200.0	2.7	-0.2	-3.7	-3.7
100.0	6.8	3.6	2.0	1.5
Mean	1.6	-1.9	-3.3	-5.0

UK & Iceland

	T+00	T+12	T+24	T+36
850.0	3.6	0.3	-1.1	-3.6
700.0	1.4	-0.9	-1.1	-4.7
500.0	-1.7	-2.9	-0.9	-3.1
300.0	-1.3	-1.5	-0.5	-0.9
250.0	-0.6	0.6	-1.4	-0.3
200.0	0.8	-0.7	-0.7	-1.5
100.0	-0.9	-4.4	-1.9	-4.7
Mean	0.2	-1.4	-1.1	-2.7

TABLE C.5

Verification against surface obs
Period= 01/06/96-14/07/96

PMSL
LAM area

T+00	T+12	T+24	T+36
4.8	-0.4	-2.0	-2.8

UK & Iceland

T+00	T+12	T+24	T+36
6.5	4.7	-1.5	-6.1

1.5m Temperature
LAM area

T+00	T+12	T+24	T+36
8.7	9.4	5.9	6.5

UK & Iceland

T+00	T+12	T+24	T+36
14.4	17.3	12.9	14.2

10m Wind
LAM area

T+00	T+12	T+24	T+36
-9.6	-10.5	-8.6	-10.4

UK & Iceland

T+00	T+12	T+24	T+36
2.5	1.6	1.1	0.6

TABLE C.6

Verification against analyses
Period= 01/06/96-14/07/96

Height
LAM area

	T+12	T+24	T+36
850.0	-4.6	1.1	-2.6
700.0	-2.5	3.7	-1.6
500.0	6.9	2.8	2.3
300.0	14.3	4.5	2.8
250.0	12.6	2.2	-2.6
200.0	5.2	-3.7	-10.9
100.0	-13.4	-16.5	-21.6
Mean	2.6	-0.8	-4.9

UK & Iceland

	T+12	T+24	T+36
850.0	6.3	5.7	-10.5
700.0	8.2	5.6	-9.7
500.0	11.0	3.5	-8.7
300.0	11.7	5.1	-5.4
250.0	11.7	5.6	-3.8
200.0	7.4	5.6	-3.0
100.0	7.0	-1.2	1.9
Mean	9.0	4.3	-5.6

TABLE C.7

Verification against analyses
Period= 01/06/96-14/07/96

Temperature
LAM area

	T+12	T+24	T+36
850.0	8.8	3.7	2.3
700.0	18.5	3.4	3.8
500.0	15.7	6.5	6.1
300.0	11.4	2.3	0.0
250.0	1.2	-2.2	-1.9
200.0	2.8	-4.0	-3.5
100.0	-6.0	-21.7	-14.9
Mean	7.5	-1.7	-1.2

UK & Iceland

	T+12	T+24	T+36
850.0	3.1	1.4	-0.8
700.0	17.5	7.7	0.9
500.0	25.0	6.8	0.0
300.0	6.3	-7.7	-6.7
250.0	-4.5	-10.4	-9.2
200.0	4.7	-0.7	1.2
100.0	-4.8	-2.7	-1.4
Mean	6.8	-0.8	-2.3

TABLE C.8

Verification against analyses
Period= 01/06/96-14/07/96

Relative humidity
AREA 2

	T+12	T+24	T+36
850.0	19.9	11.1	9.2
700.0	18.1	12.4	10.2
500.0	16.0	9.5	6.5
Mean	18.0	11.0	8.6

NH

	T+12	T+24	T+36
850.0	4.4	1.6	1.4
700.0	8.4	4.7	5.1
500.0	2.6	-1.4	-4.9
Mean	5.1	1.6	0.5

TABLE C.9

Verification against analyses
Period= 01/06/96-14/07/96

Wind
LAM area

	T+12	T+24	T+36
850.0	-3.5	-5.8	-4.1
700.0	-0.5	-2.4	-1.1
300.0	1.9	2.7	3.1
300.0	0.3	-0.7	0.3
250.0	-4.1	-5.4	-5.2
200.0	-9.1	-9.7	-9.0
100.0	-4.3	-5.3	-5.9
Mean	-2.8	-3.8	-3.1

UK & Iceland

	T+12	T+24	T+36
850.0	2.9	1.6	-6.5
700.0	3.3	-0.2	-6.5
300.0	2.2	0.6	-5.2
300.0	2.6	-2.1	-3.0
250.0	-3.3	-0.8	-5.2
200.0	-7.0	-2.2	-7.3
100.0	-0.6	-2.3	0.0
Mean	0.0	-0.8	-4.8

TABLE C.10

Verification against analyses
Period= 01/06/96-14/07/96

PMSL
LAM area

T+12	T+24	T+36
-2.6	-0.1	-1.2

UK & Iceland

T+12	T+24	T+36
5.2	2.7	-9.8

10m Wind
LAM area

T+12	T+24	T+36
1.5	1.4	0.9

UK & Iceland

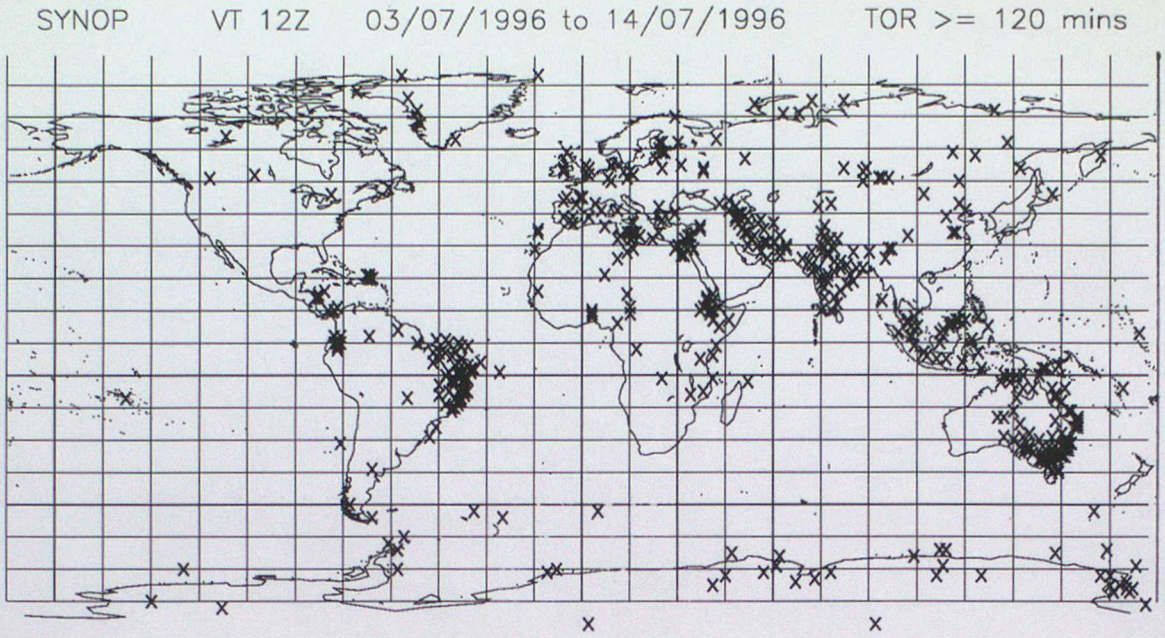
T+12	T+24	T+36
3.6	3.7	-2.6

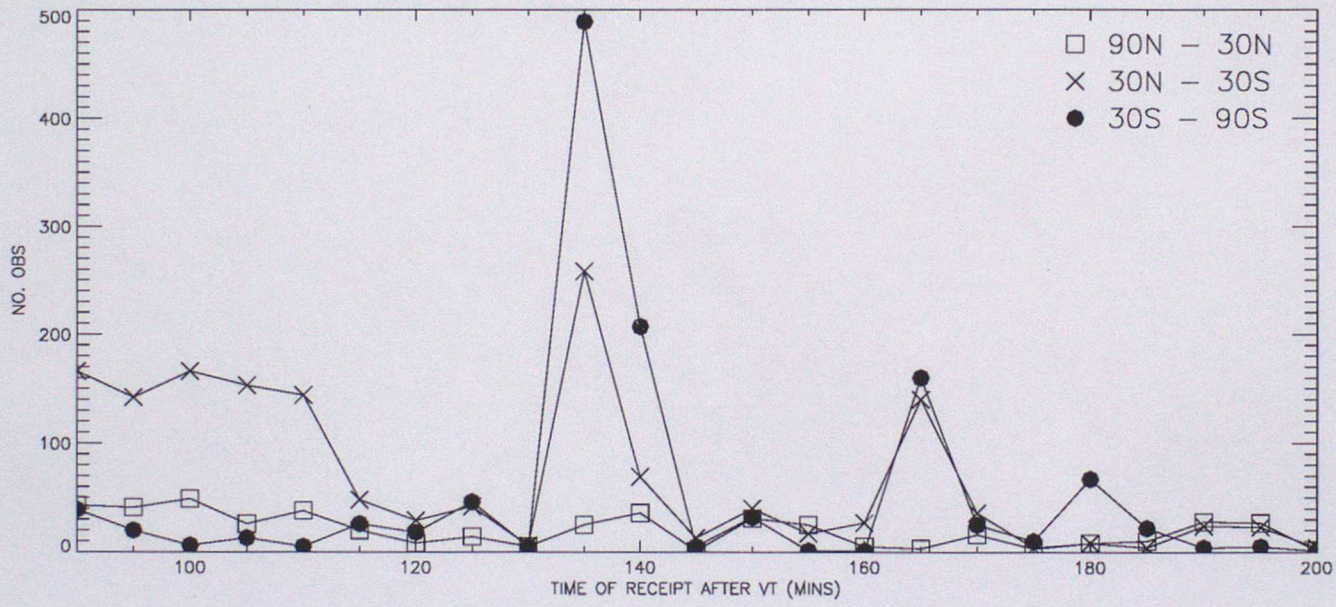
1.5m Temperature
LAM area

T+12	T+24	T+36
13.7	9.2	8.6

UK & Iceland

T+12	T+24	T+36
12.5	13.5	12.1


SYNOP VT 12Z 03/07/1996 to 14/07/1996 TOR >= 120 mins


90N – 30N
30N – 30S
30S – 90S
NO. OBS
TIME OF RECEIPT AFTER VT (MINS)

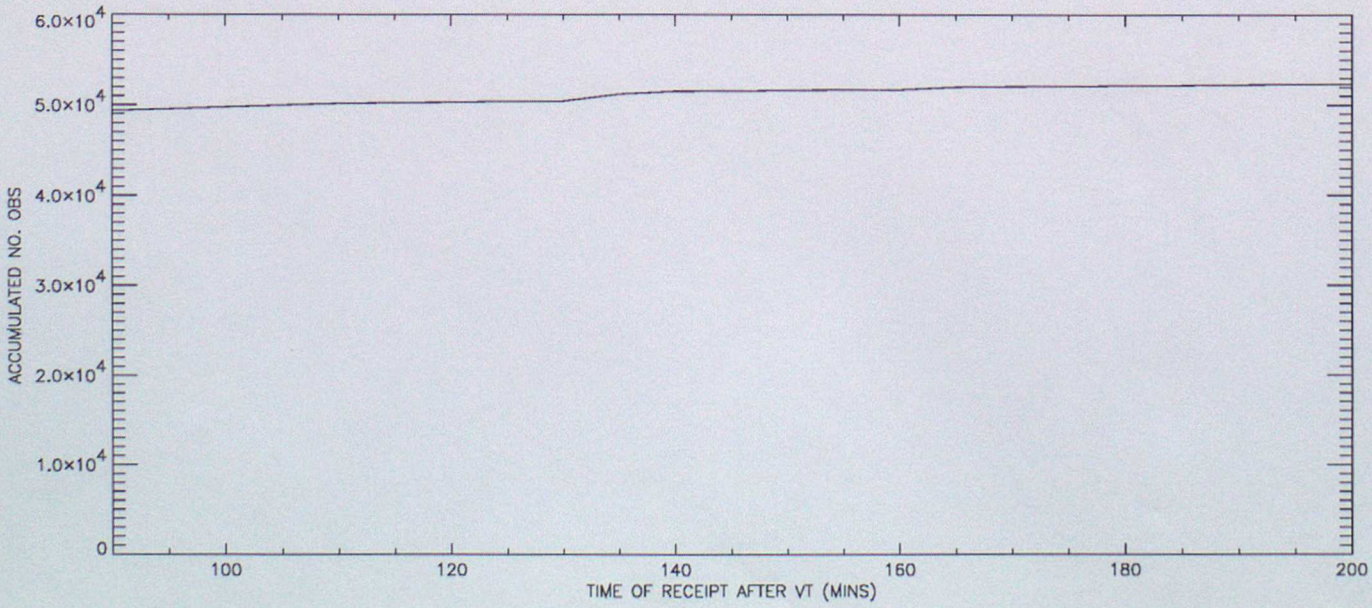

ACCUMULATED NO. OBS
TIME OF RECEIPT AFTER VT (MINS)

FIGURE 2.1

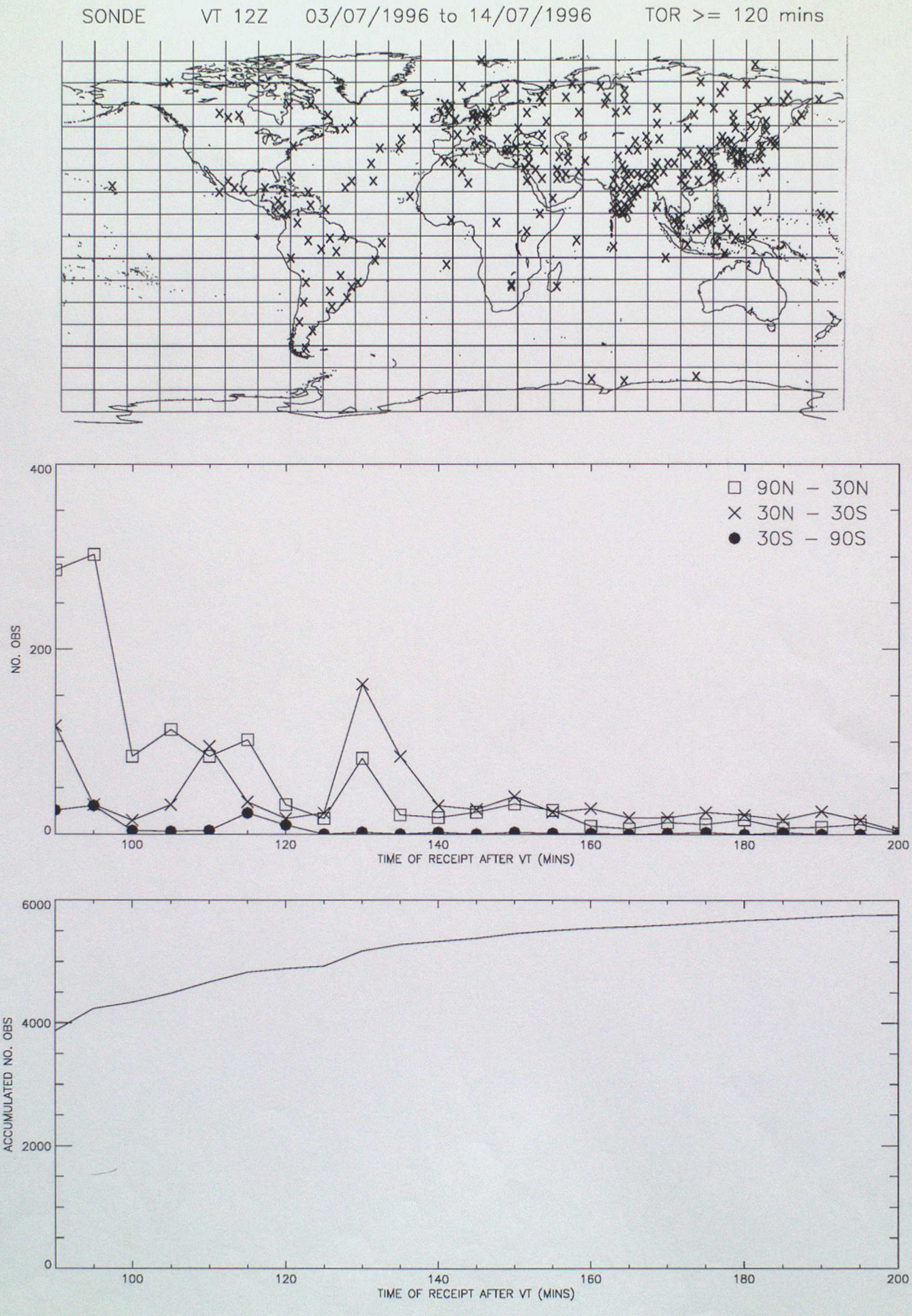

SONDE VT 12Z 03/07/1996 to 14/07/1996 TOR >= 120 mins
90N – 30N
30N – 30S
30S – 90S
NO. OBS
TIME OF RECEIPT AFTER VT (MINS)
ACCUMULATED NO. OBS
TIME OF RECEIPT AFTER VT (MINS)

FIGURE 2.2

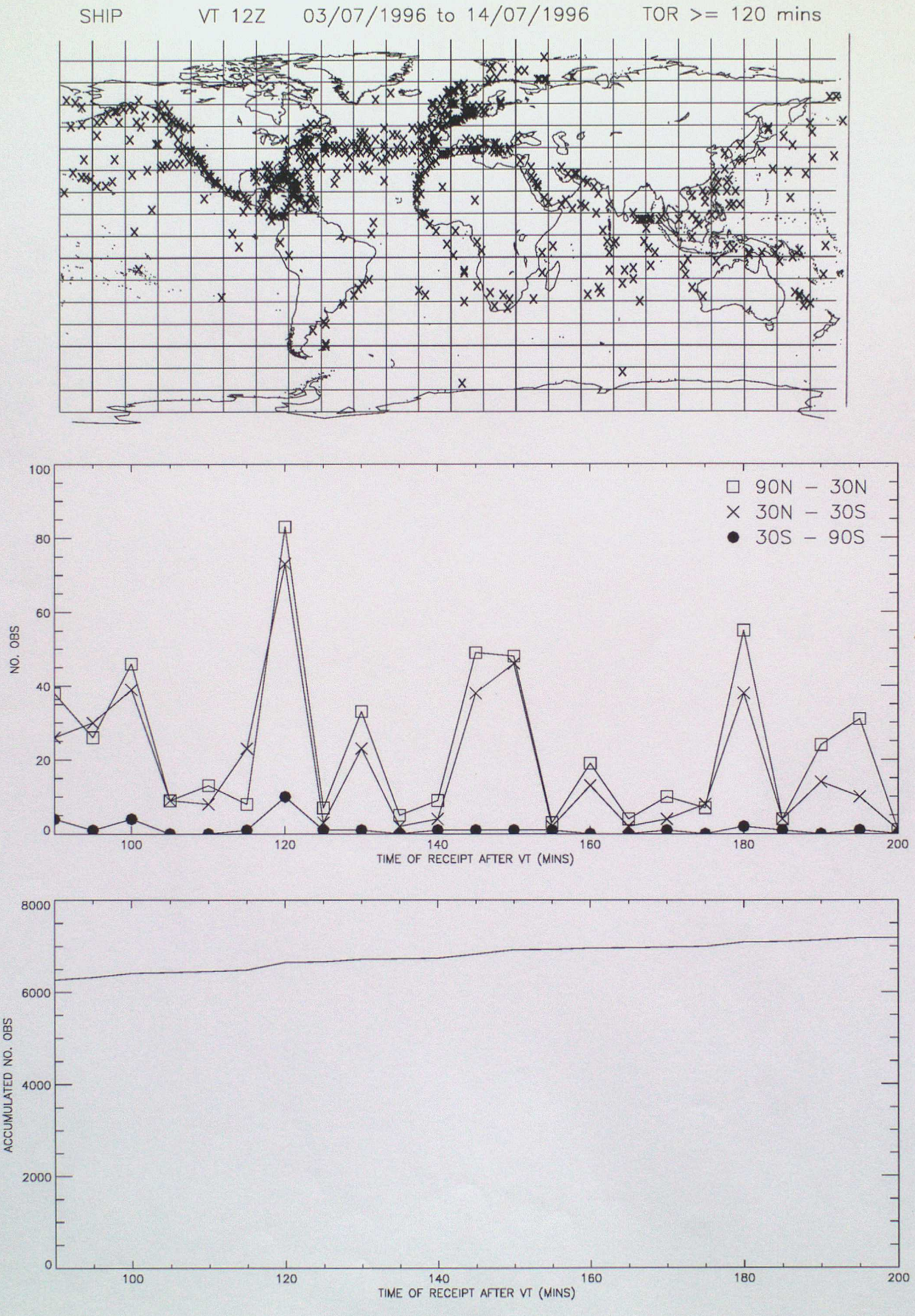
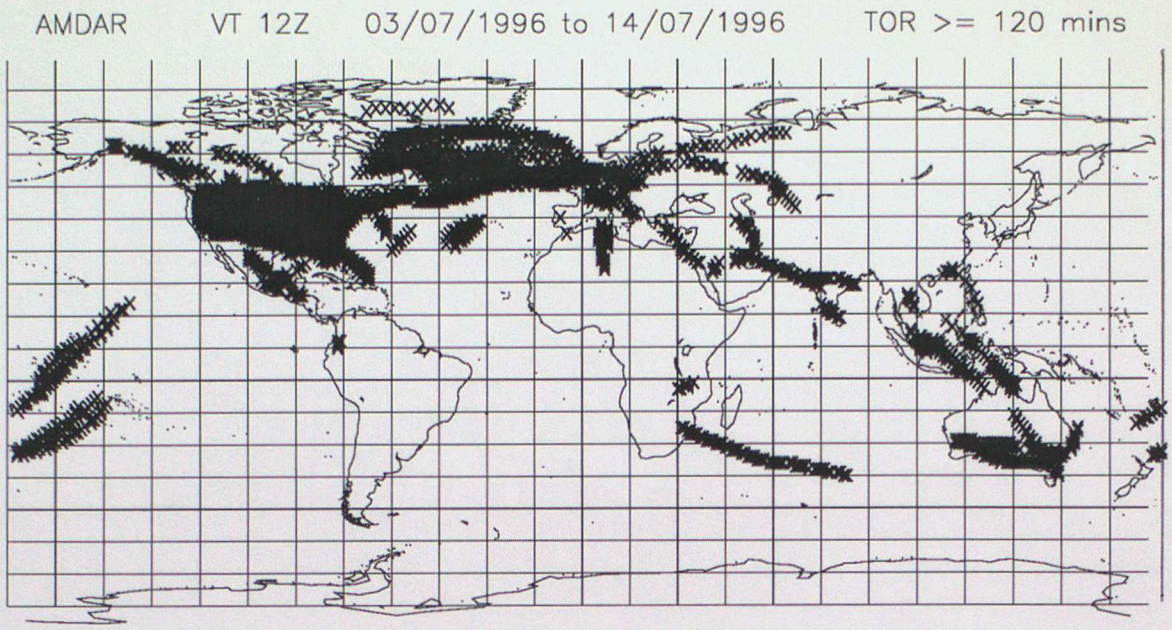
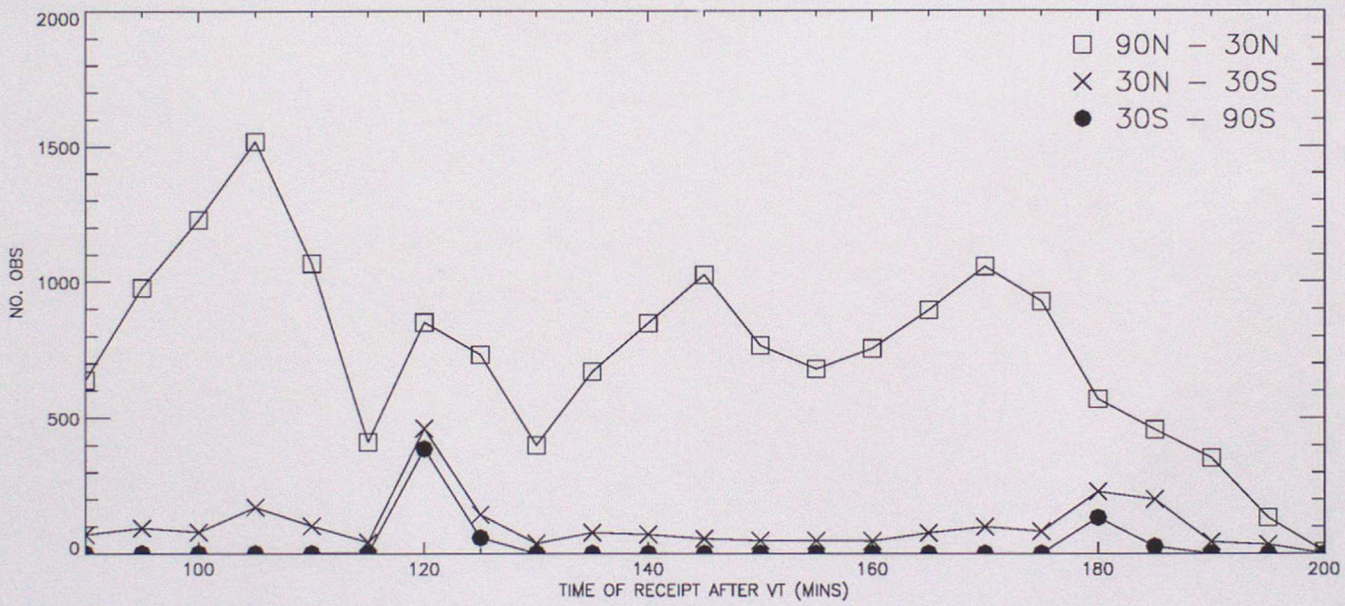

SHIP
VT 12Z
03/07/1996 to 14/07/1996
TOR >= 120 mins
90N - 30N
30N - 30S
30S - 90S
NO. OBS
TIME OF RECEIPT AFTER VT (MINS)
ACCUMULATED NO. OBS
TIME OF RECEIPT AFTER VT (MINS)

FIGURE 2.3


AMDAR VT 12Z 03/07/1996 to 14/07/1996 TOR >= 120 mins


90N – 30N
30N – 30S
30S – 90S
NO. OBS
2000
1500
1000
500
0
100
120
140
160
180
200
TIME OF RECEIPT AFTER VT (MINS)

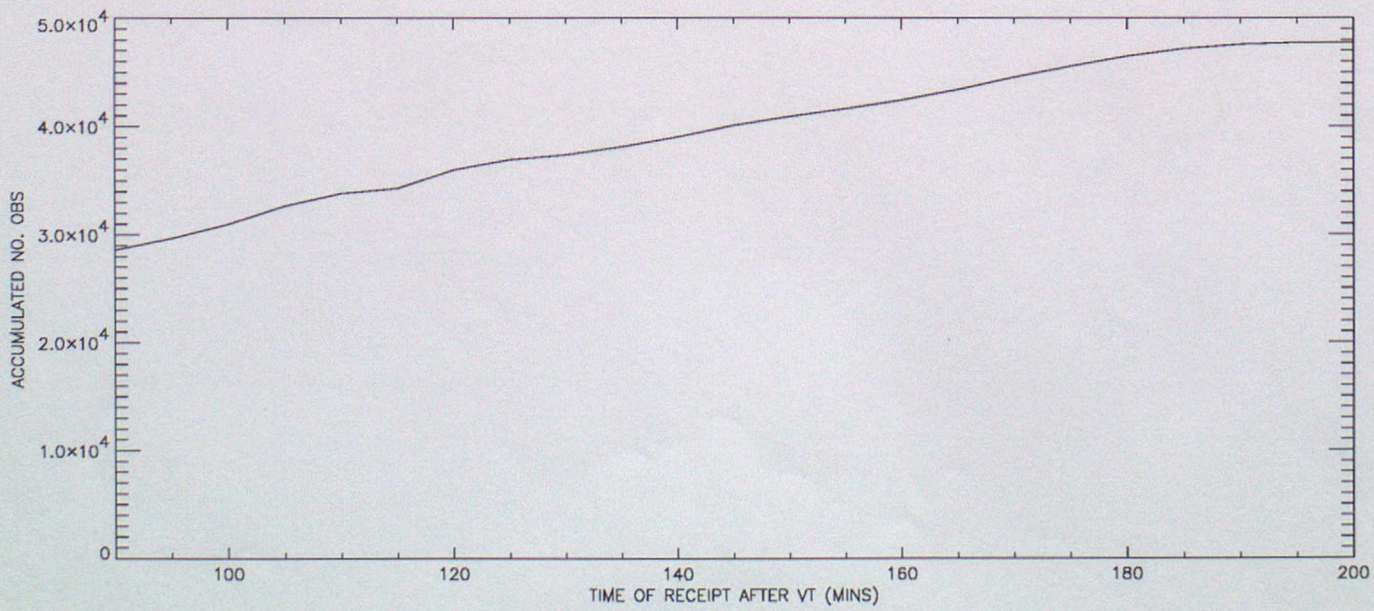
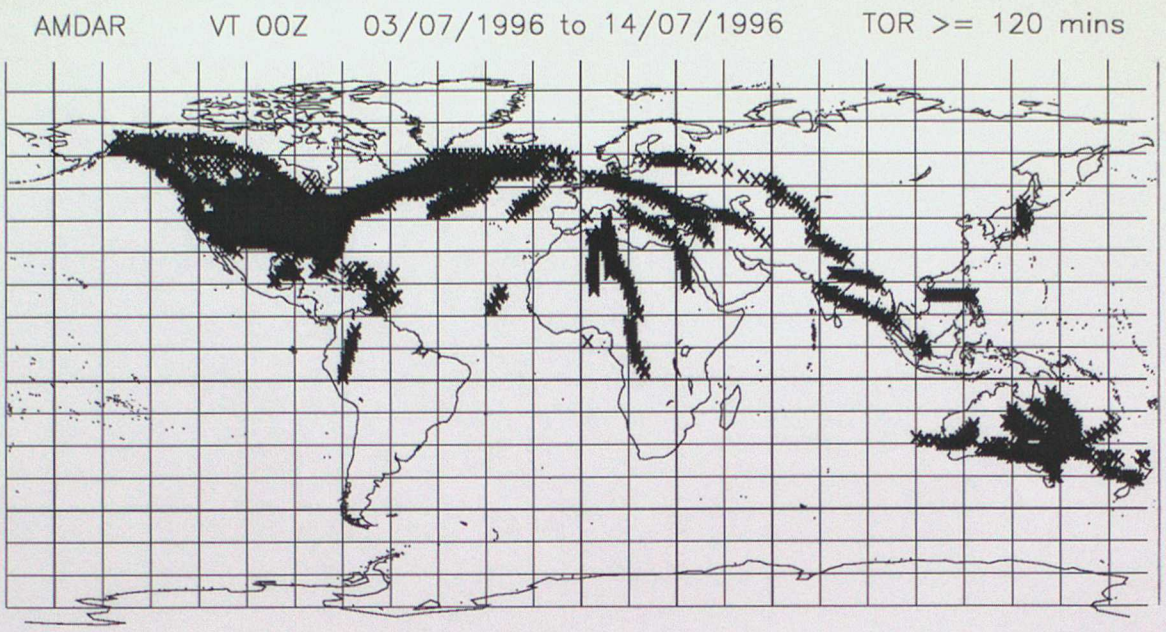
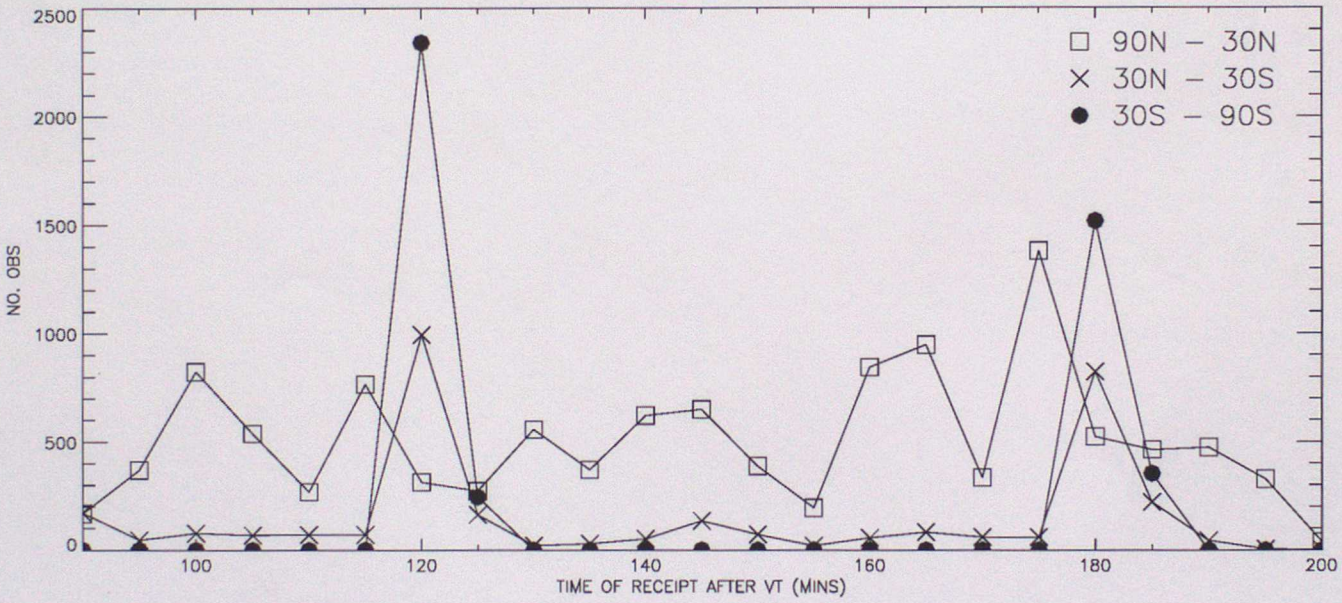

ACCUMULATED NO. OBS
5.0×10^4
4.0×10^4
3.0×10^4
2.0×10^4
1.0×10^4
0
100
120
140
160
180
200
TIME OF RECEIPT AFTER VT (MINS)

FIGURE 2.4


AMDAR VT 00Z 03/07/1996 to 14/07/1996 TOR >= 120 mins


90N – 30N
30N – 30S
30S – 90S
NO. OBS
TIME OF RECEIPT AFTER VT (MINS)

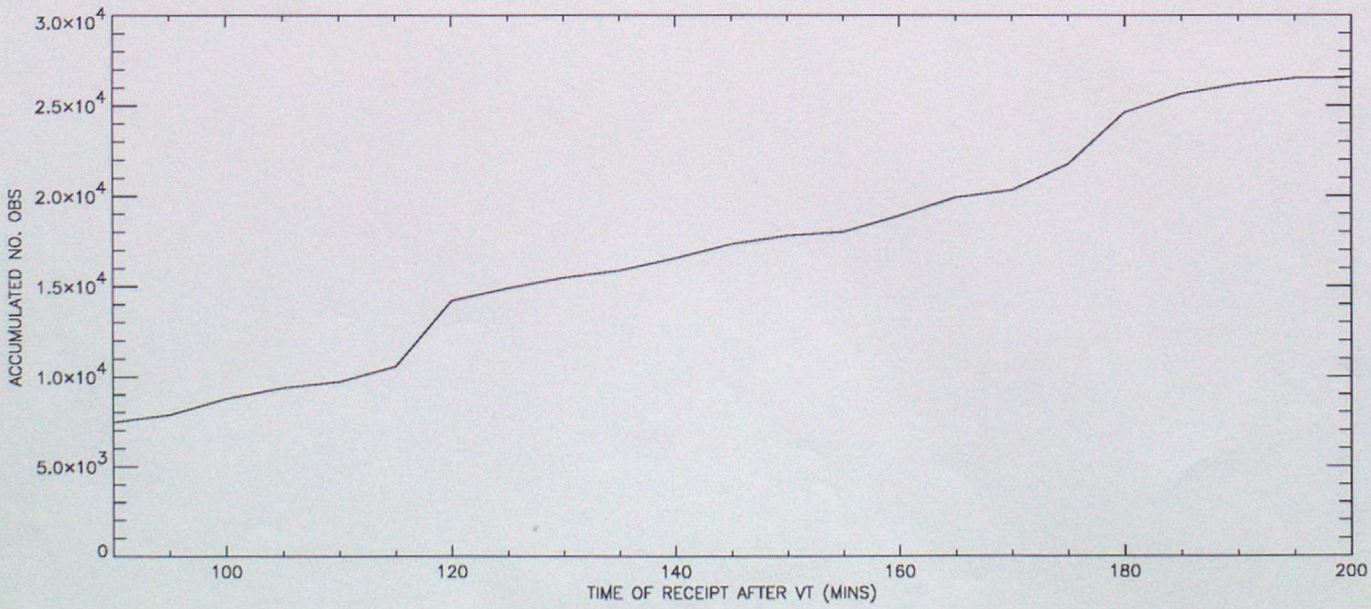
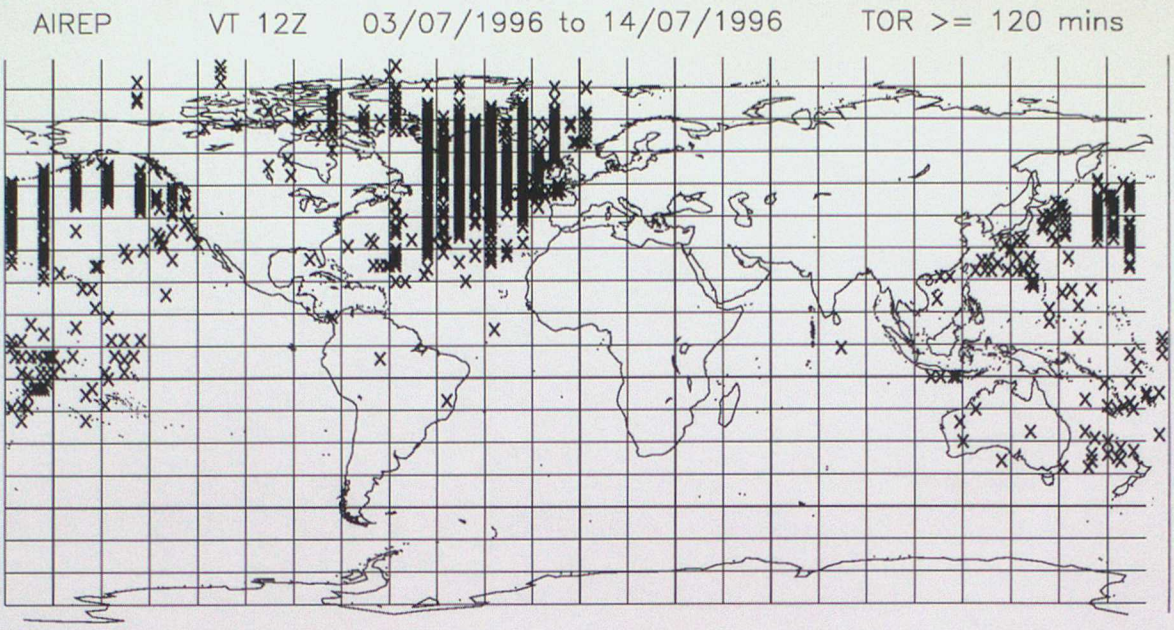
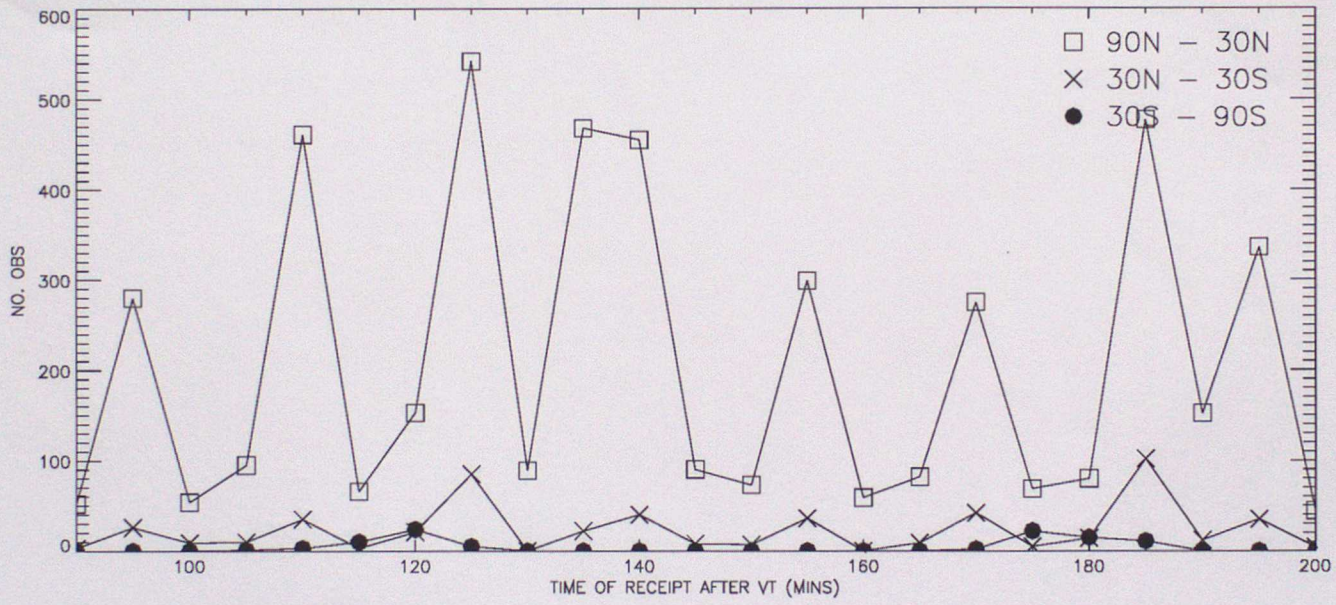

ACCUMULATED NO. OBS
TIME OF RECEIPT AFTER VT (MINS)

FIGURE 2.5


AIREP VT 12Z 03/07/1996 to 14/07/1996 TOR >= 120 mins


90N – 30N
30N – 30S
30S – 90S
NO. OBS
TIME OF RECEIPT AFTER VT (MINS)

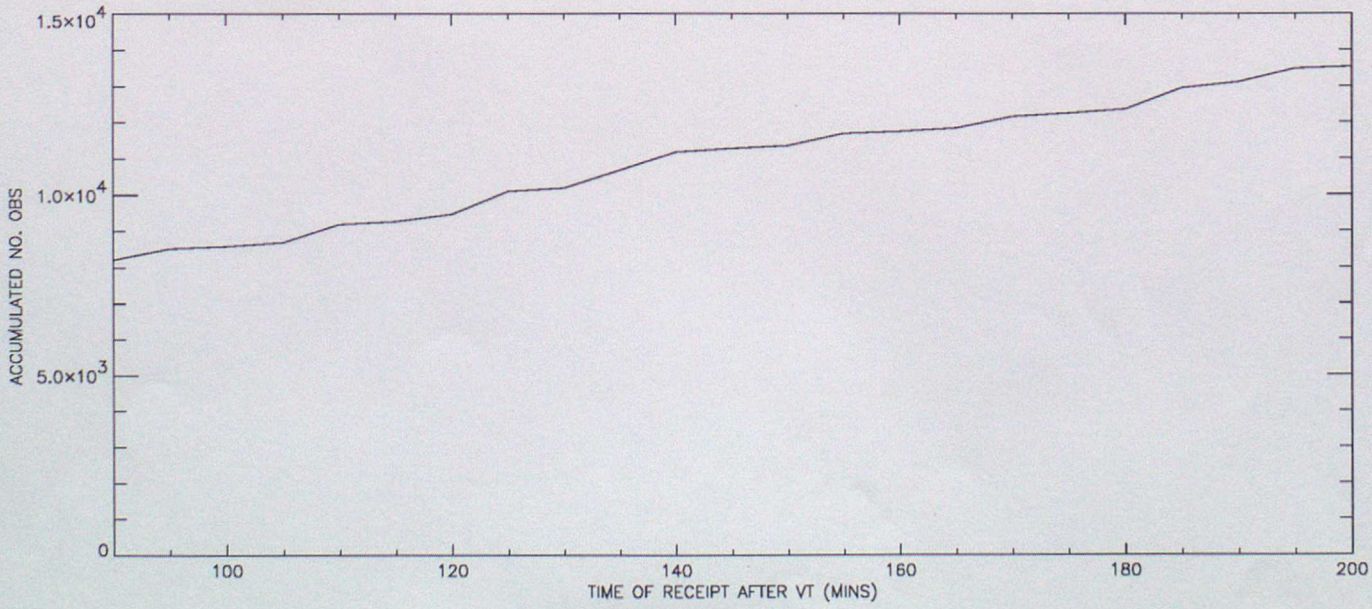
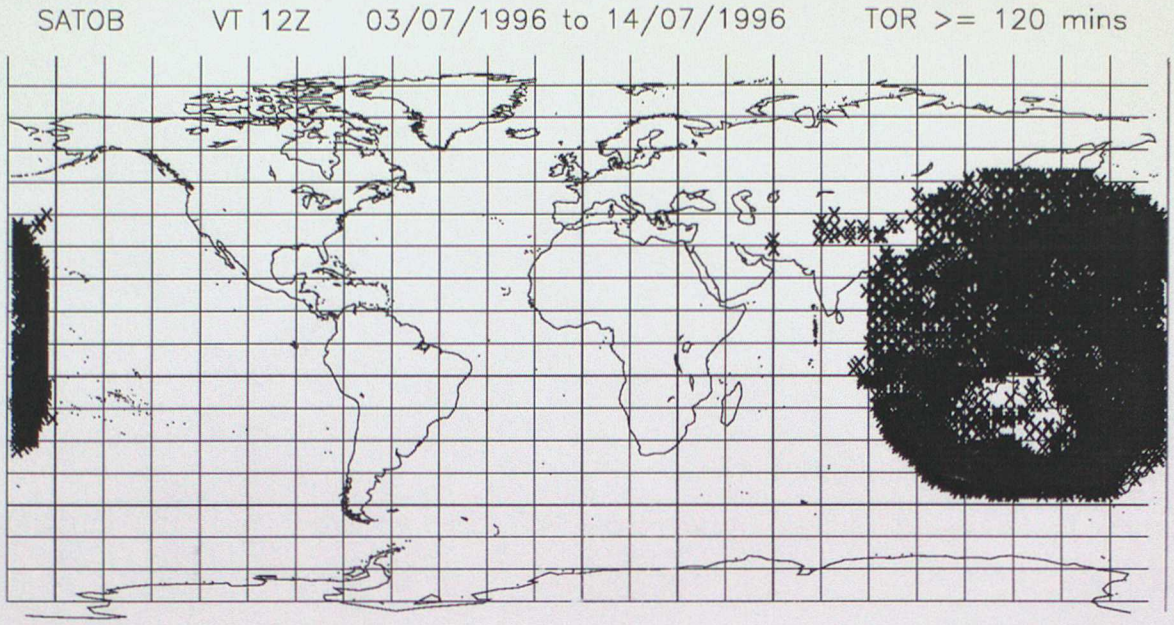
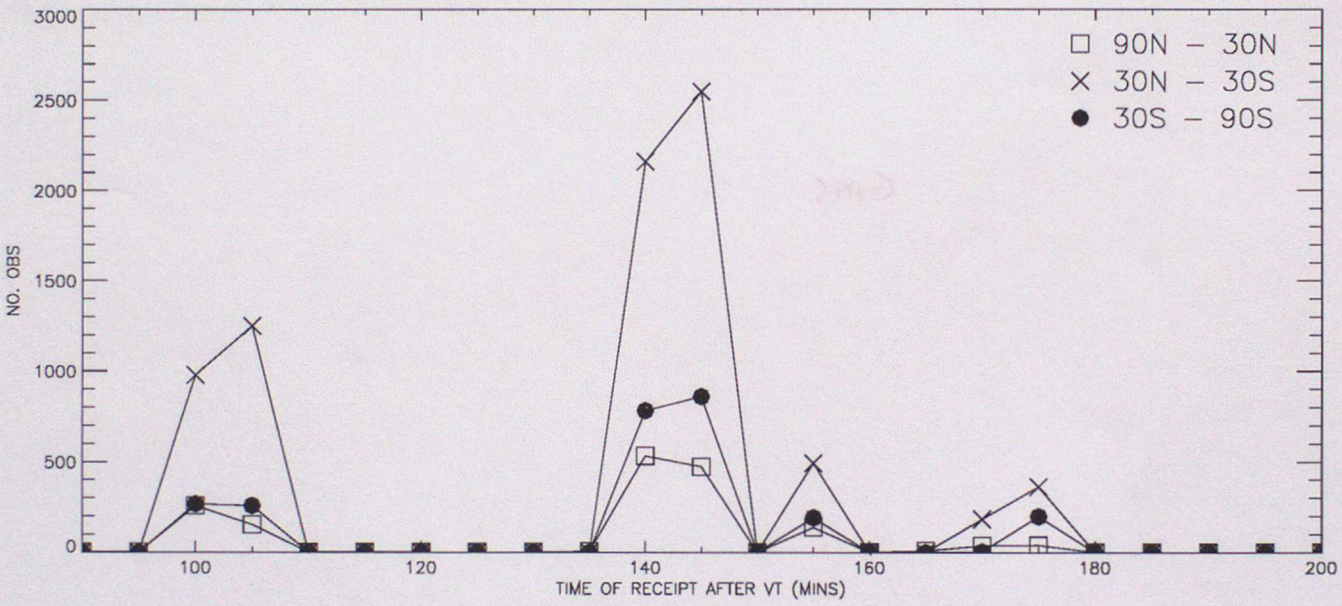

ACCUMULATED NO. OBS
TIME OF RECEIPT AFTER VT (MINS)

FIGURE 2.6


SATOB VT 12Z 03/07/1996 to 14/07/1996 TOR >= 120 mins


90N – 30N
30N – 30S
30S – 90S
NO. OBS
TIME OF RECEIPT AFTER VT (MINS)

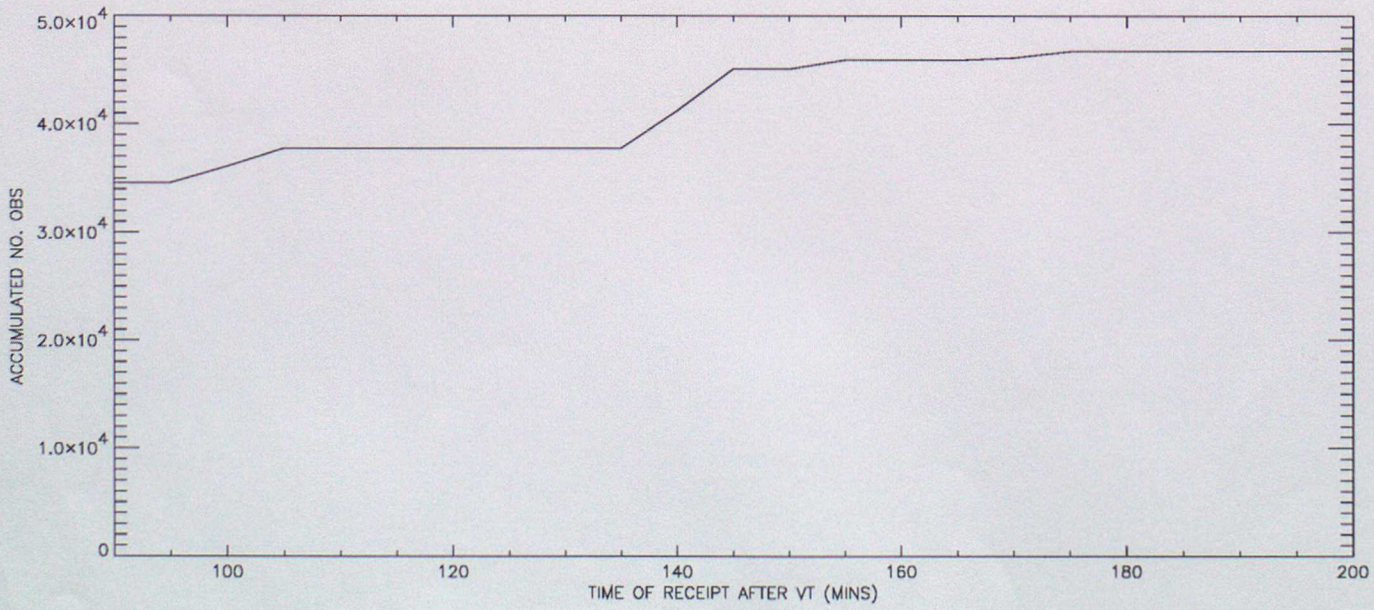
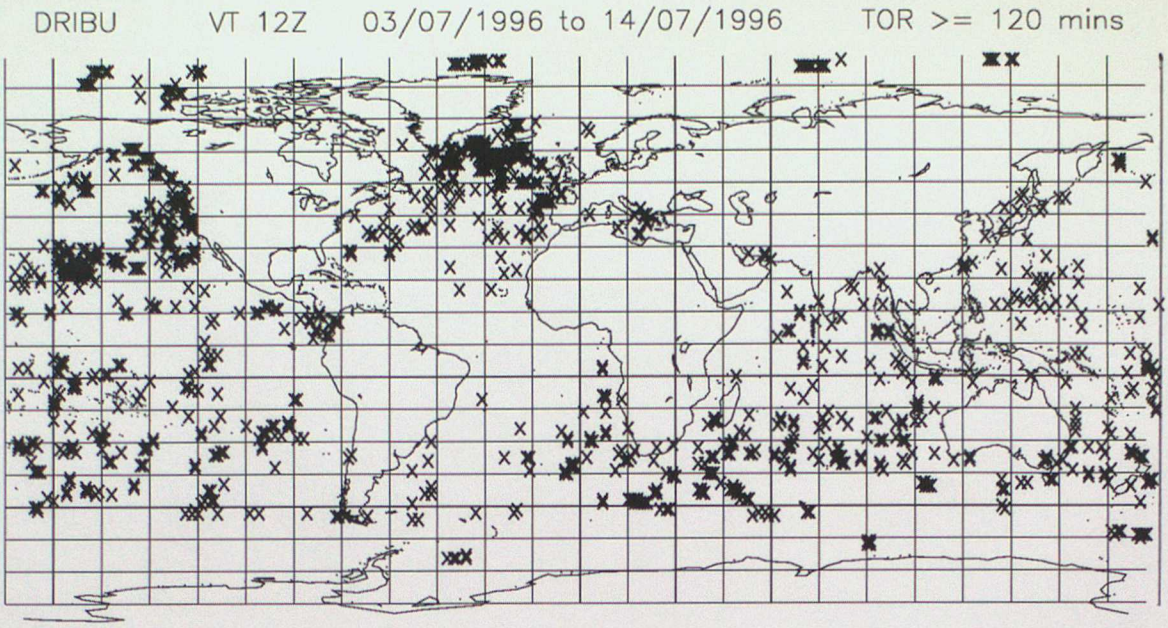
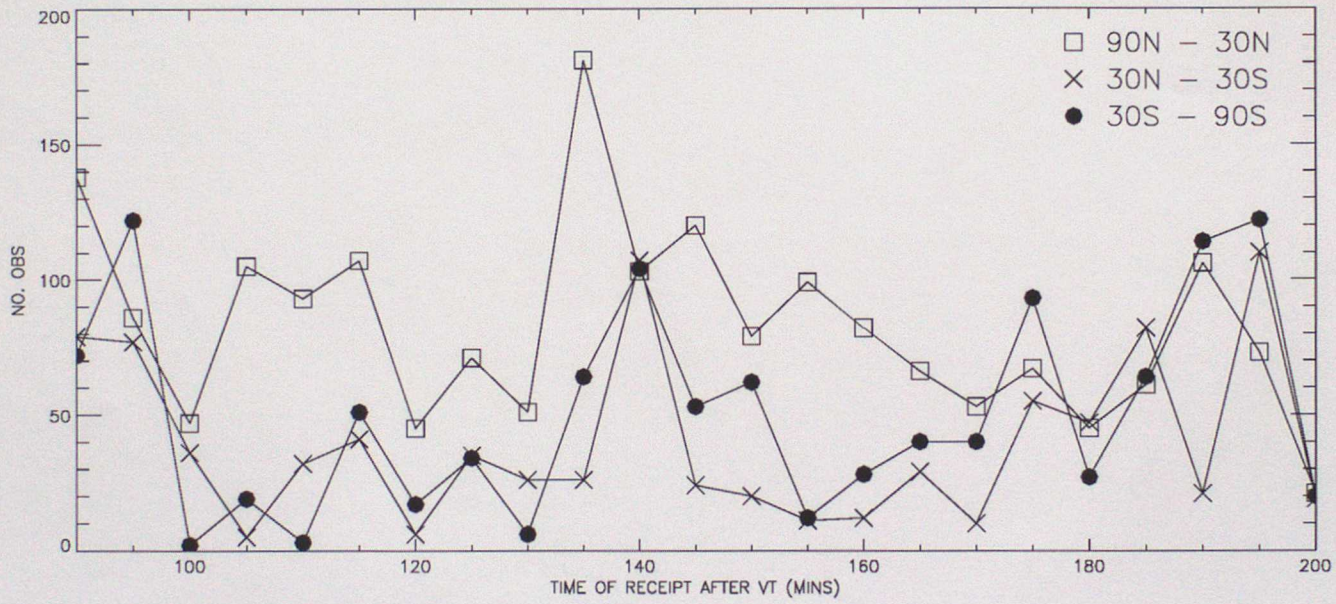

ACCUMULATED NO. OBS
TIME OF RECEIPT AFTER VT (MINS)

FIGURE 2.7


DRIBU VT 12Z 03/07/1996 to 14/07/1996 TOR >= 120 mins


90N – 30N
30N – 30S
30S – 90S
NO. OBS
TIME OF RECEIPT AFTER VT (MINS)

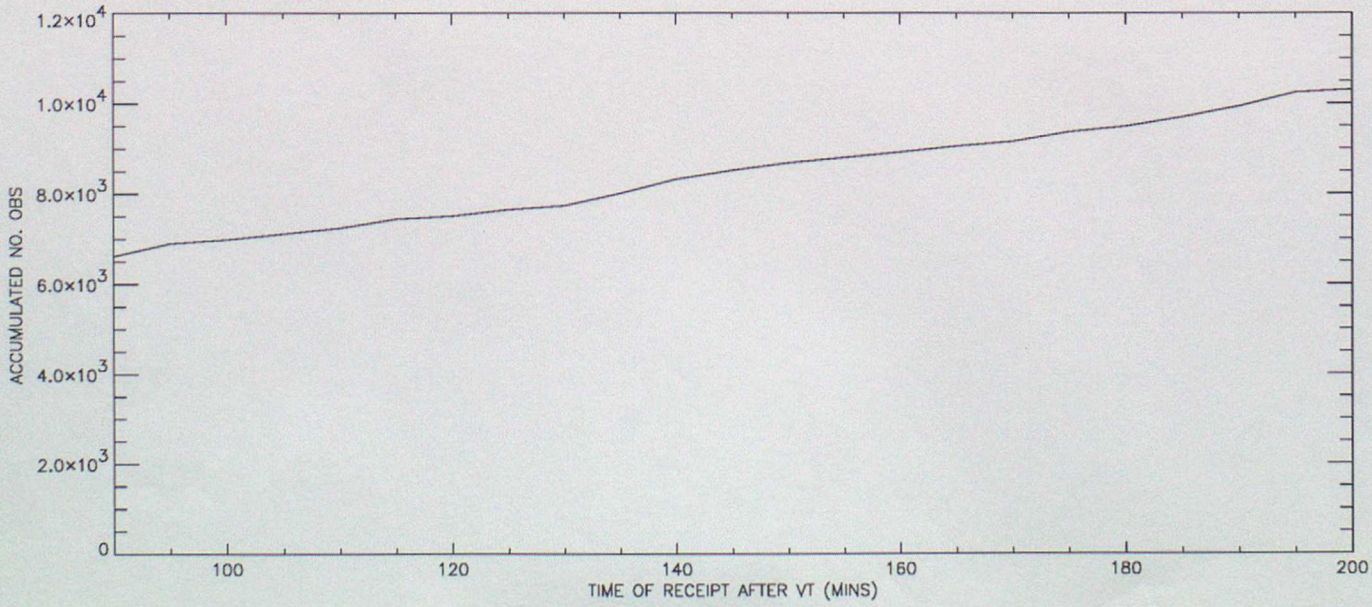
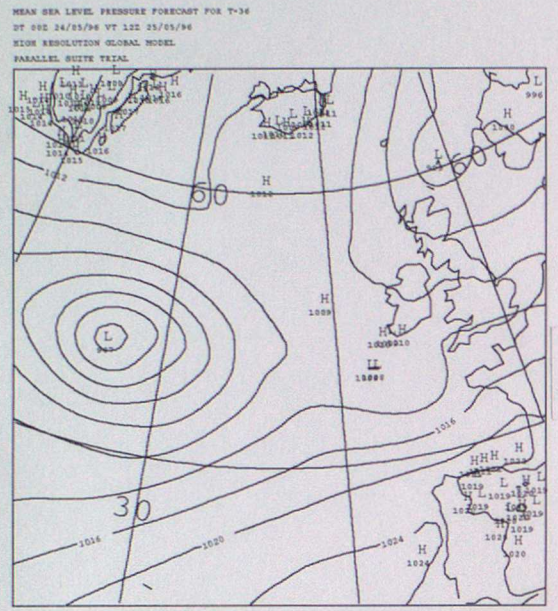
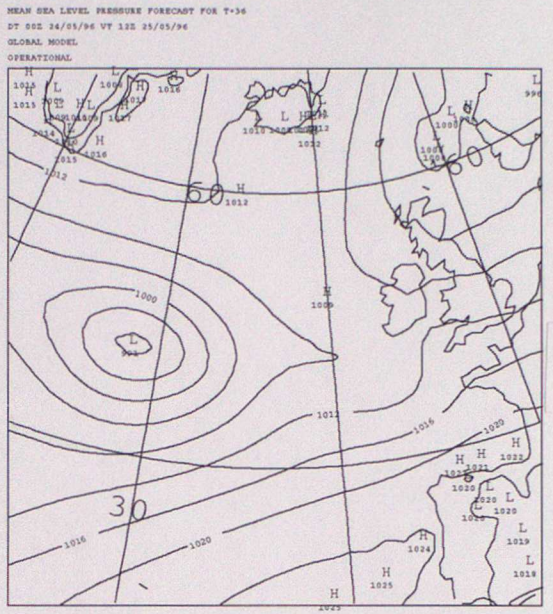

ACCUMULATED NO. OBS
TIME OF RECEIPT AFTER VT (MINS)

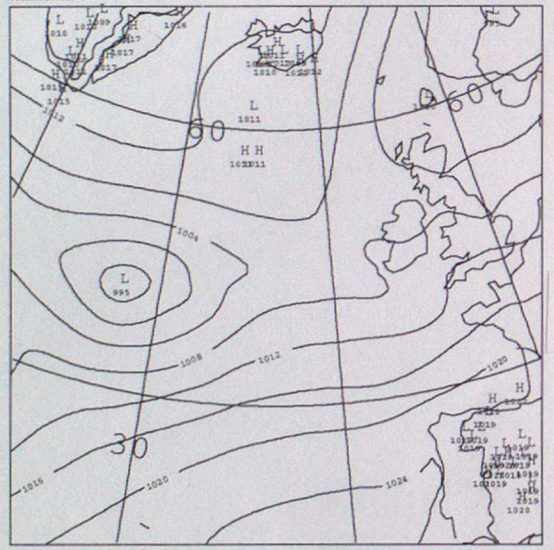
FIGURE 2.8



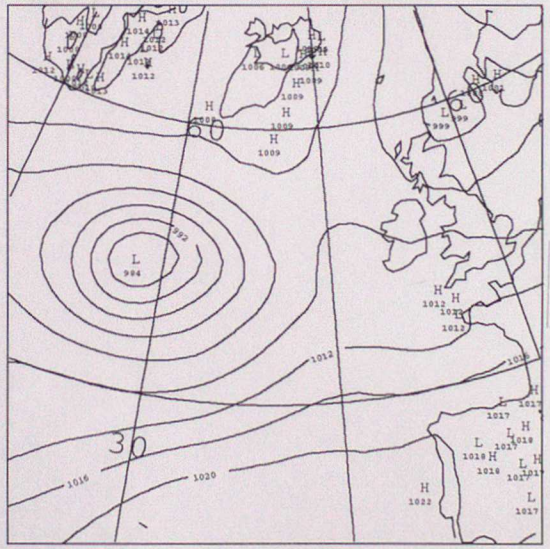
a



b

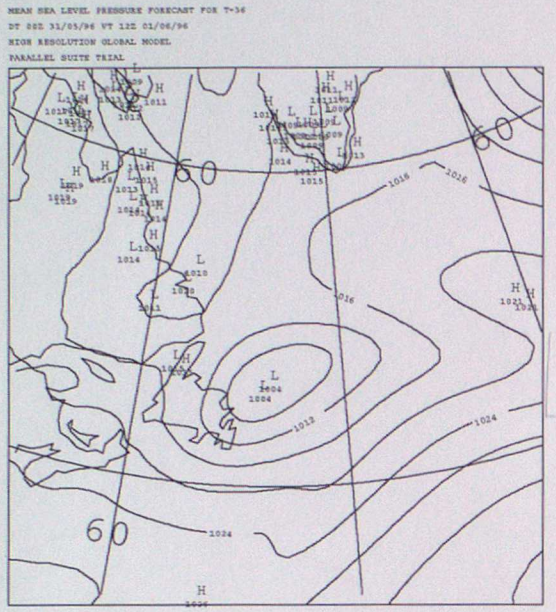


c

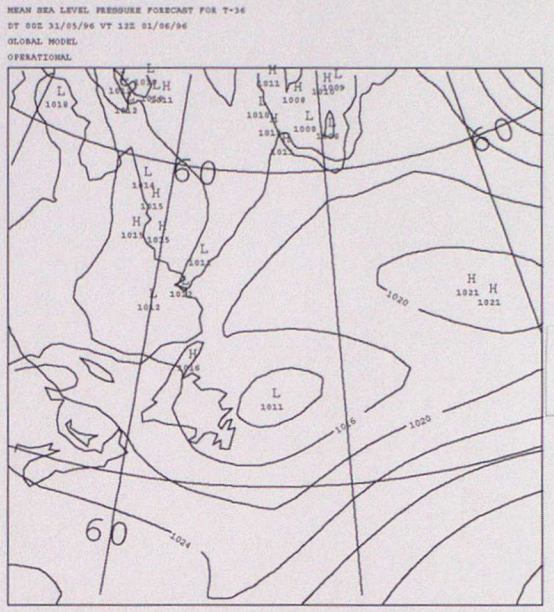


d

FIGURE 3.1



a



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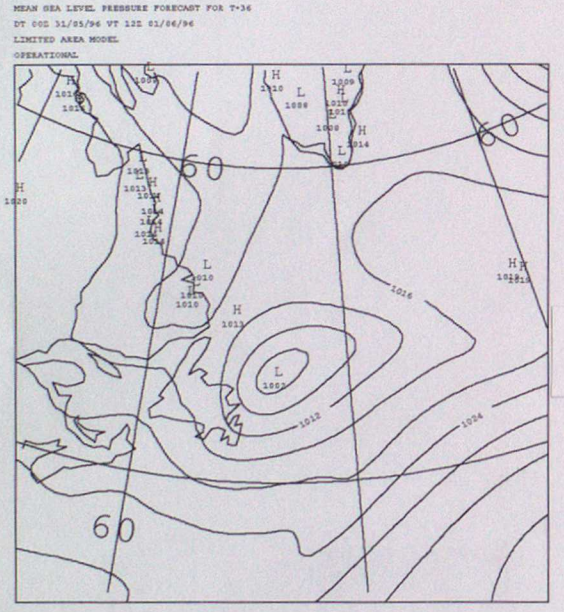
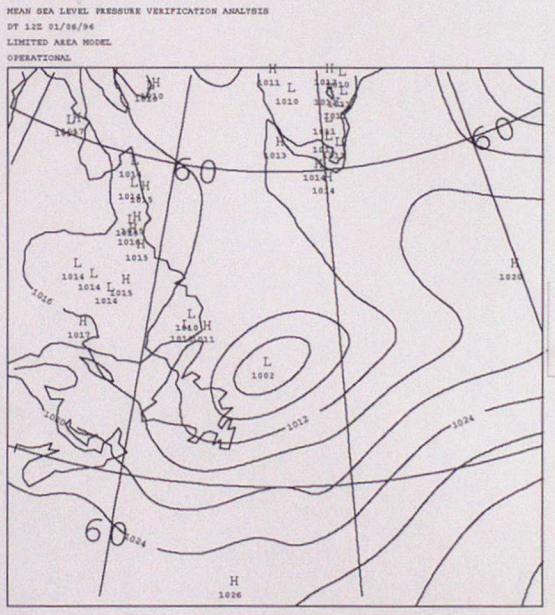
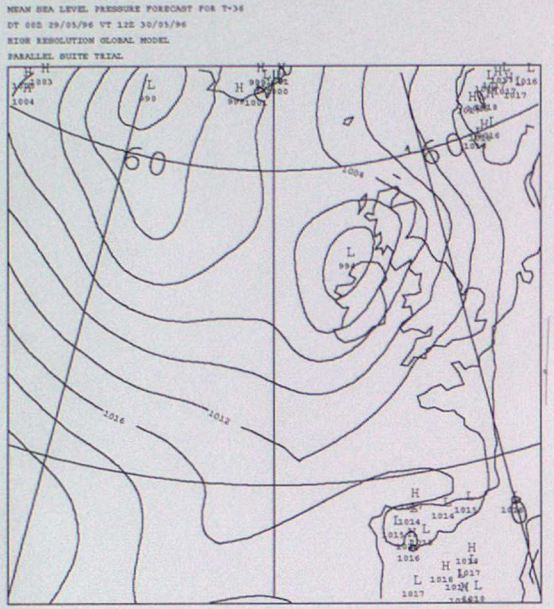


c

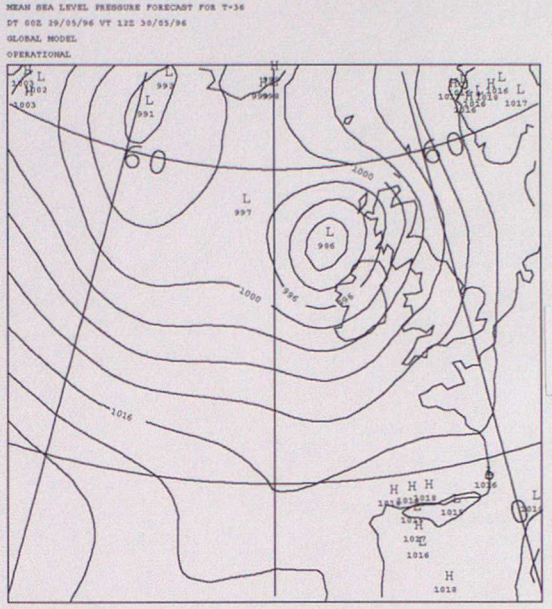


d

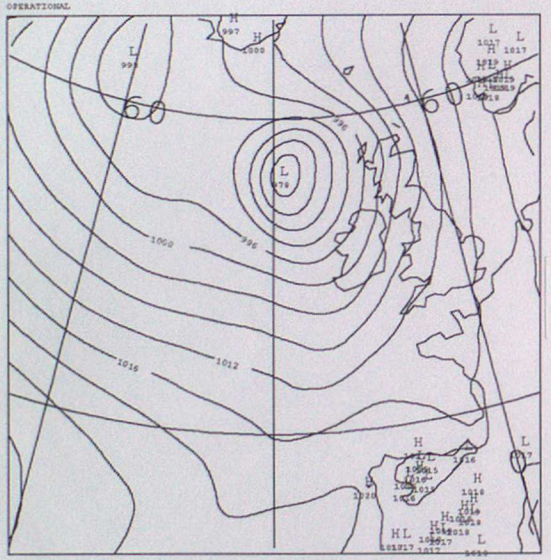
FIGURE 3.2



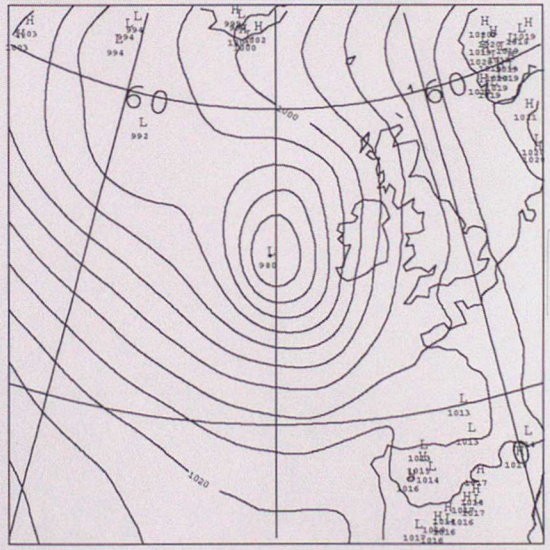
a



b



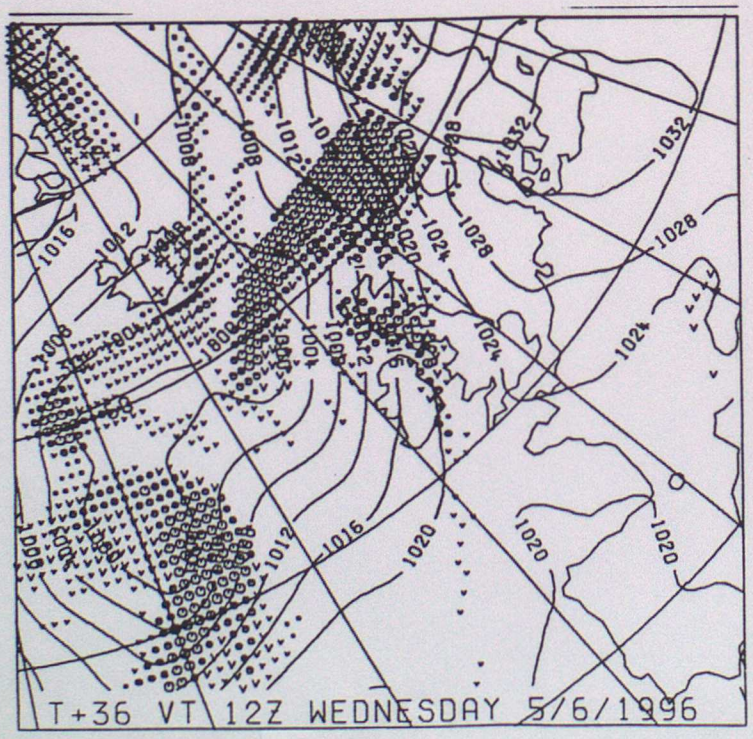
c



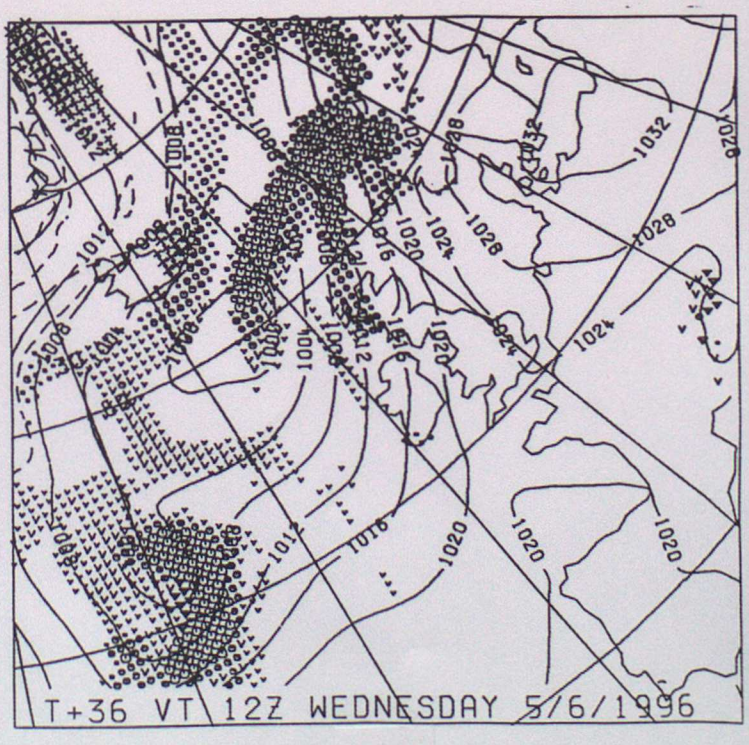
d

FIGURE 3.3

a

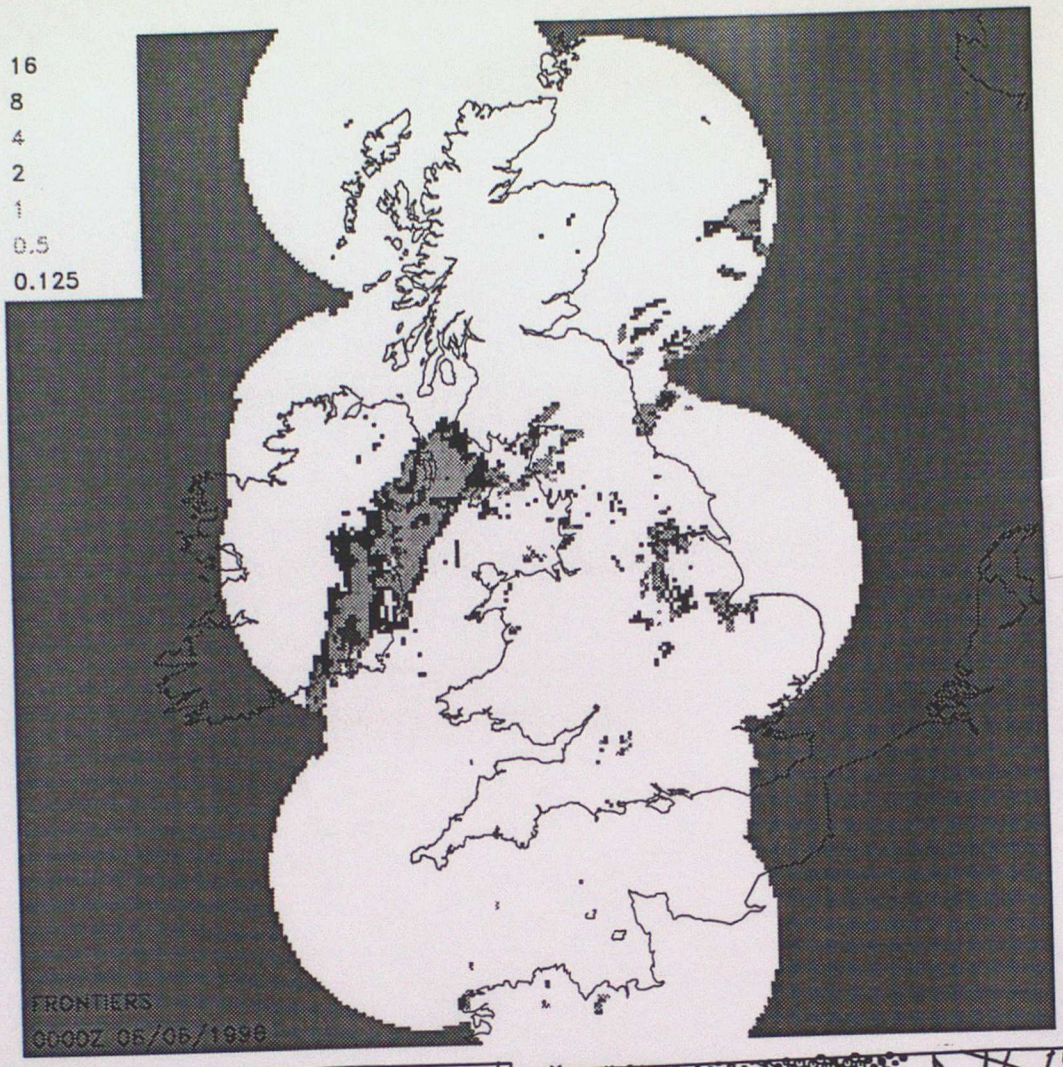


b



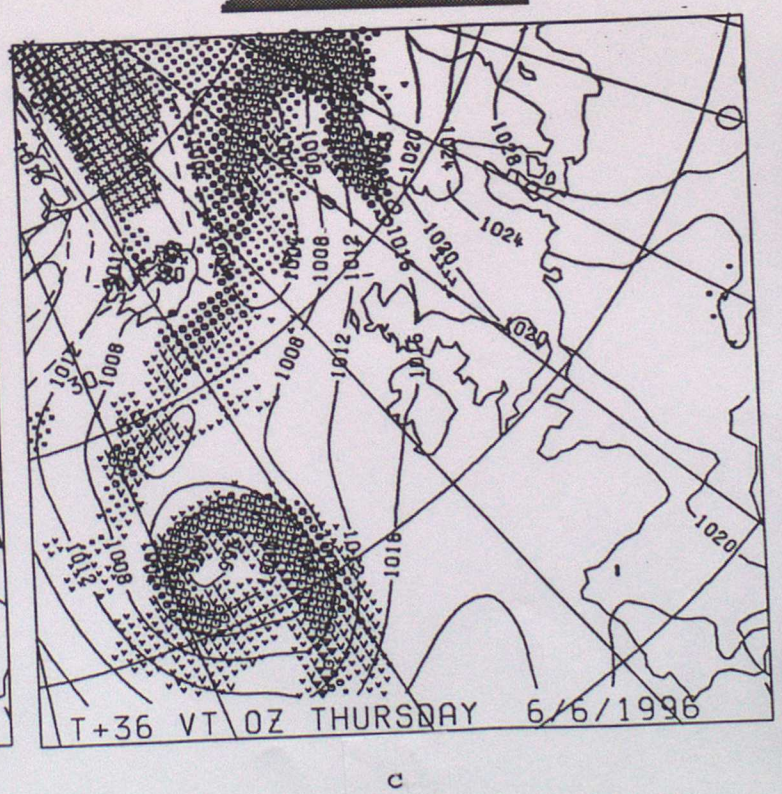
c

FIGURE 3.4



a

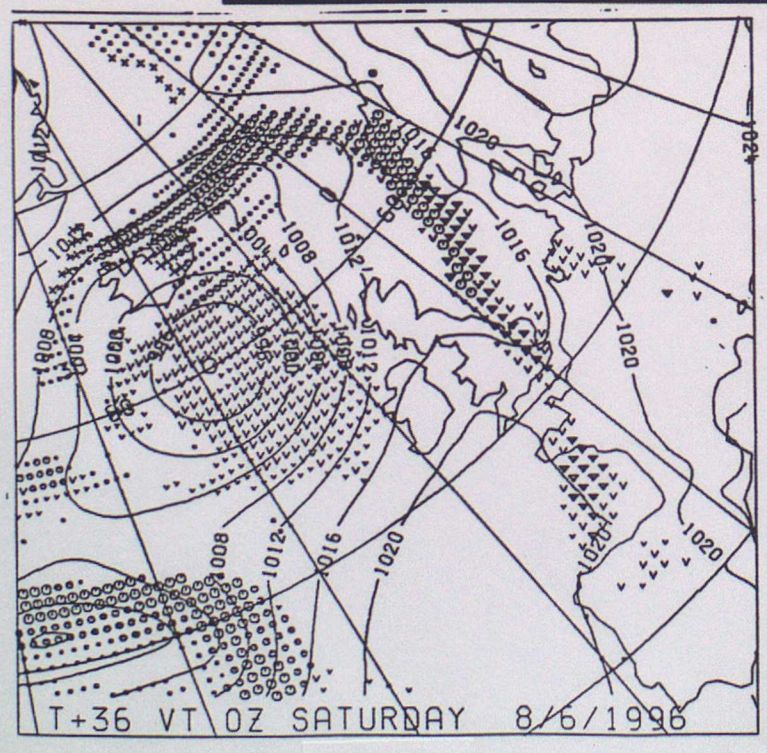
b



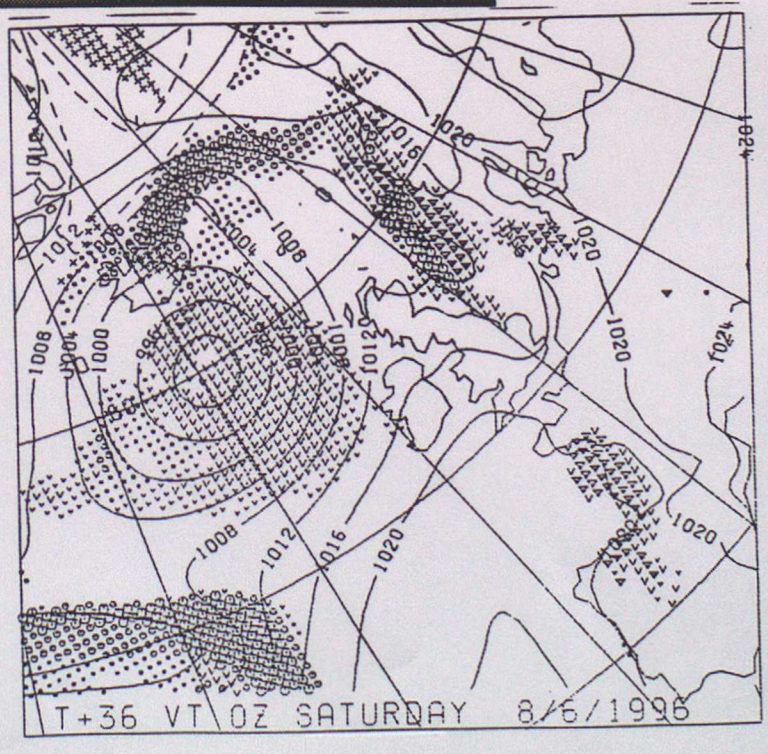
c

FIGURE 3.5

a

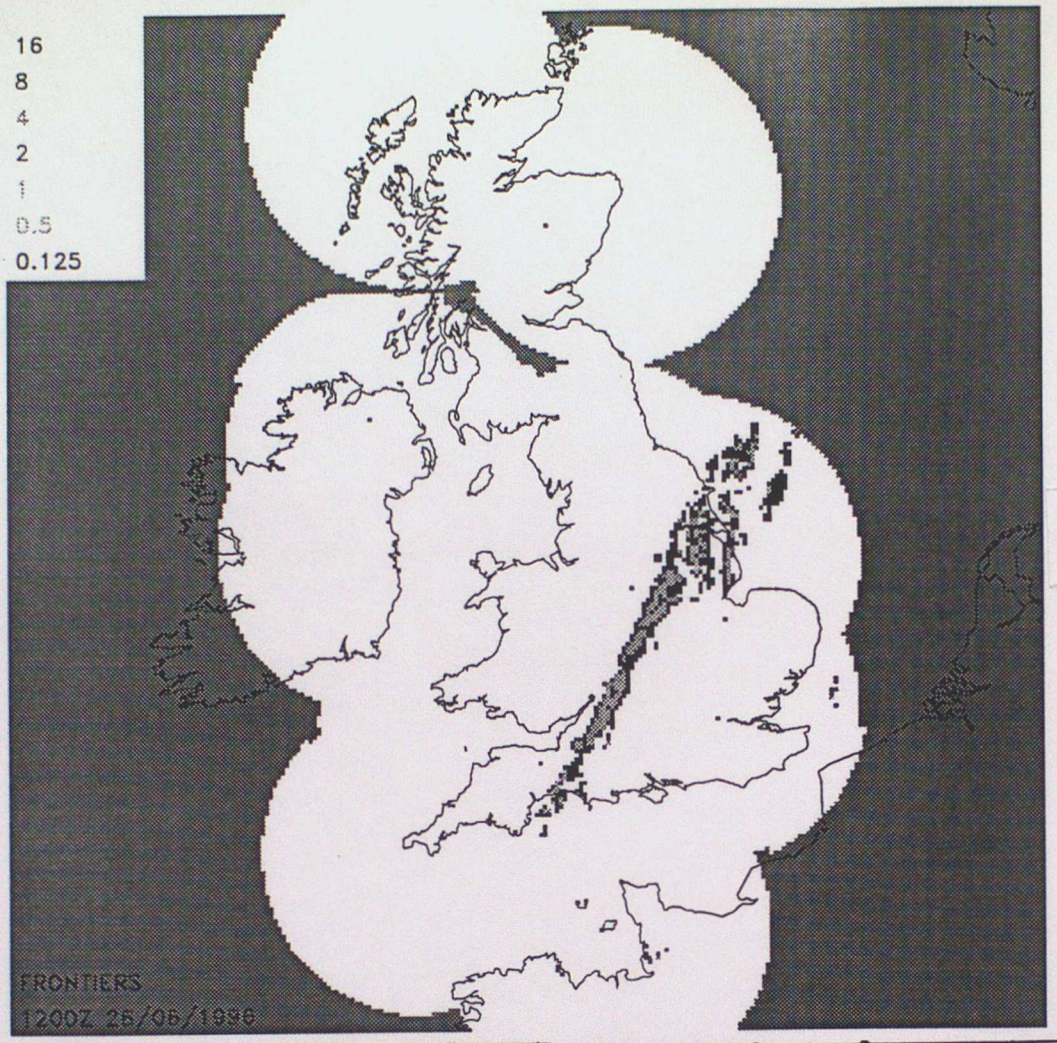


b

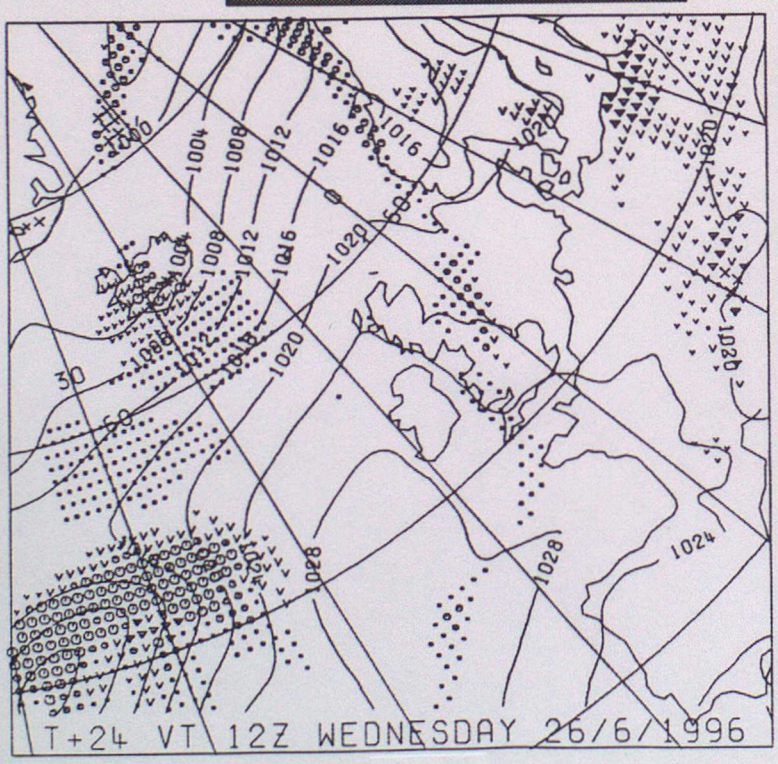


c

FIGURE 3.6



a



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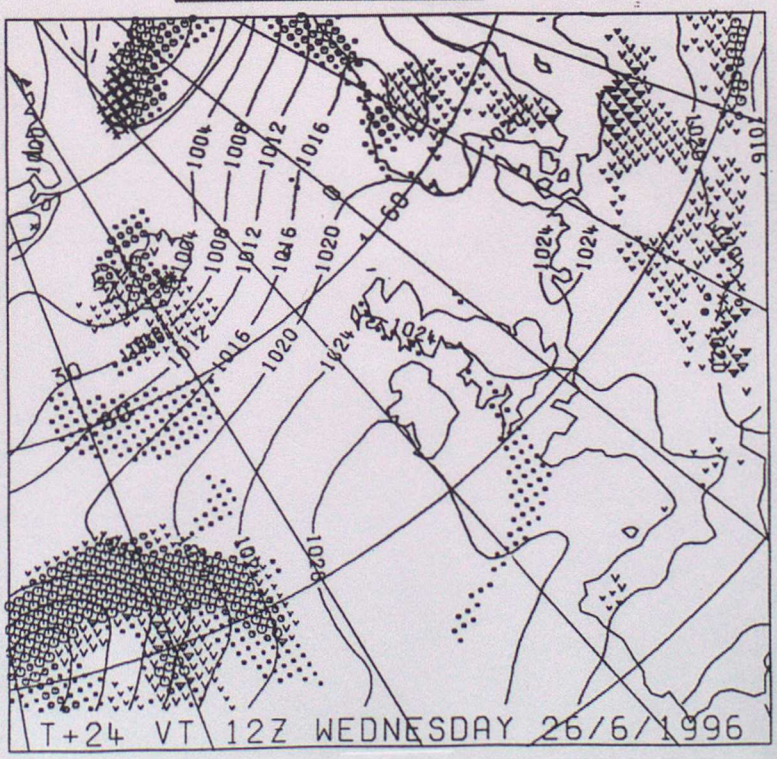
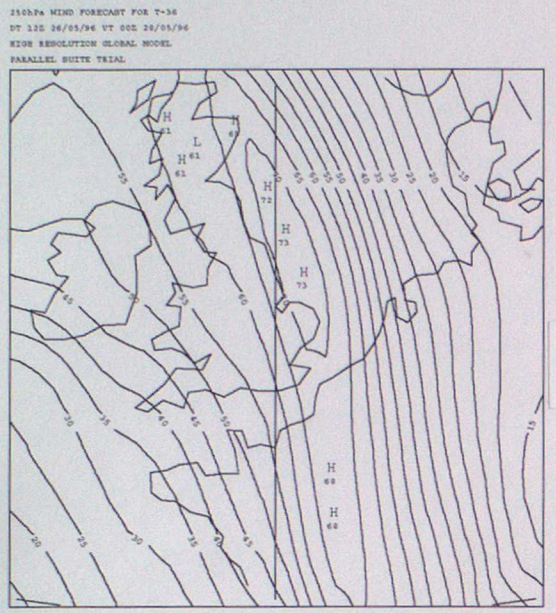


c

FIGURE 3.7



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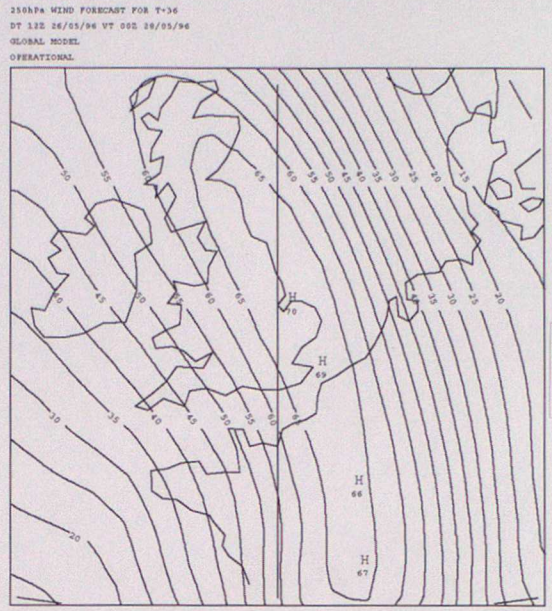

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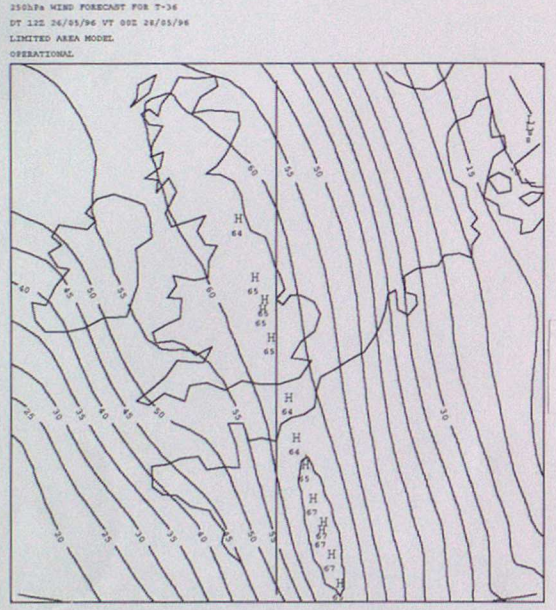

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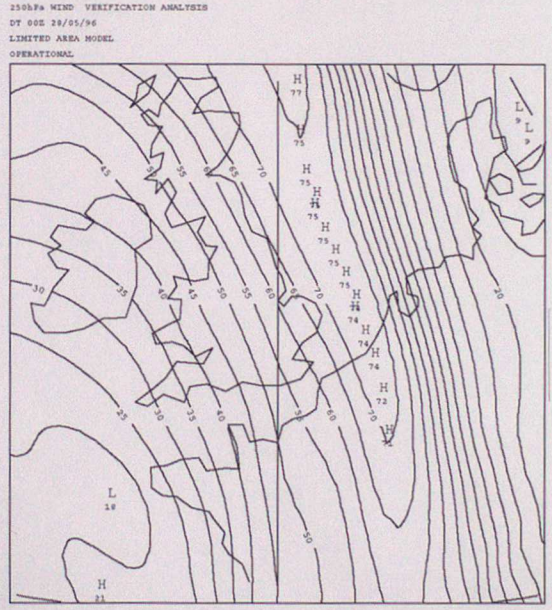


d

FIGURE 3.8

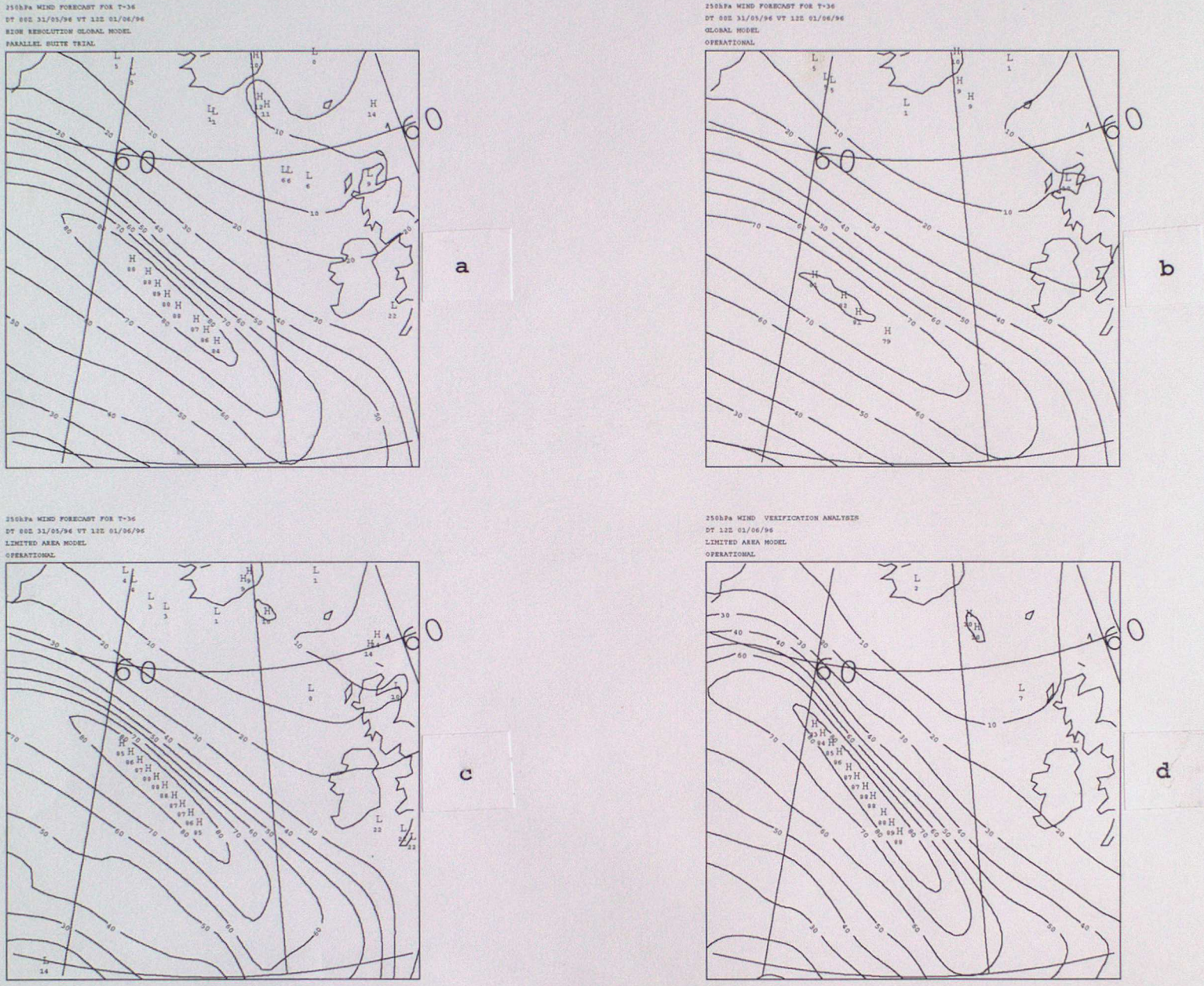
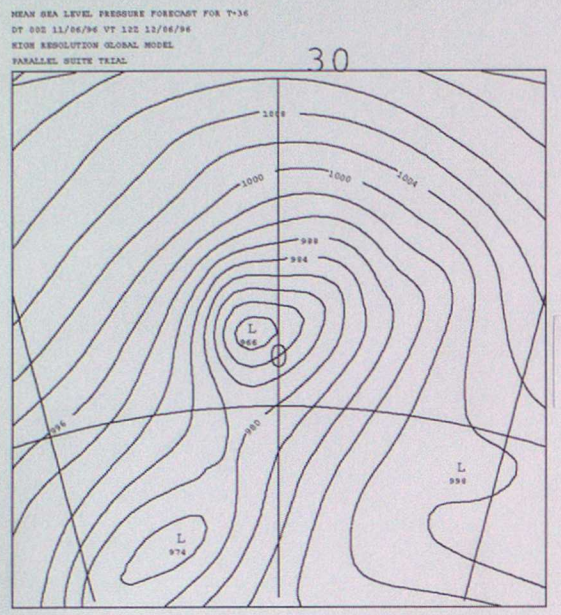
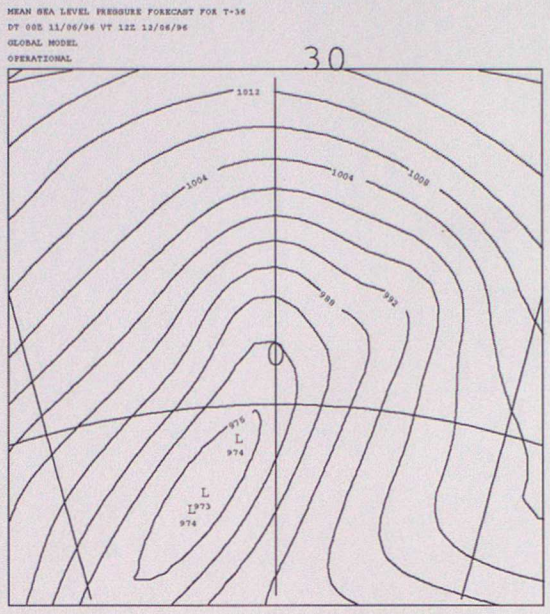

250hPa WIND FORECAST FOR T+36
DT 00Z 31/05/96 VT 12Z 01/06/96
HIGH RESOLUTION GLOBAL MODEL
PARALLEL SUITE TRIAL
a
250hPa WIND FORECAST FOR T+36
DT 00Z 31/05/96 VT 12Z 01/06/96
GLOBAL MODEL
OPERATIONAL
b
250hPa WIND FORECAST FOR T+36
DT 00Z 31/05/96 VT 12Z 01/06/96
LIMITED AREA MODEL
OPERATIONAL
c
250hPa WIND VERIFICATION ANALYSIS
DT 12Z 01/06/96
LIMITED AREA MODEL
OPERATIONAL
d

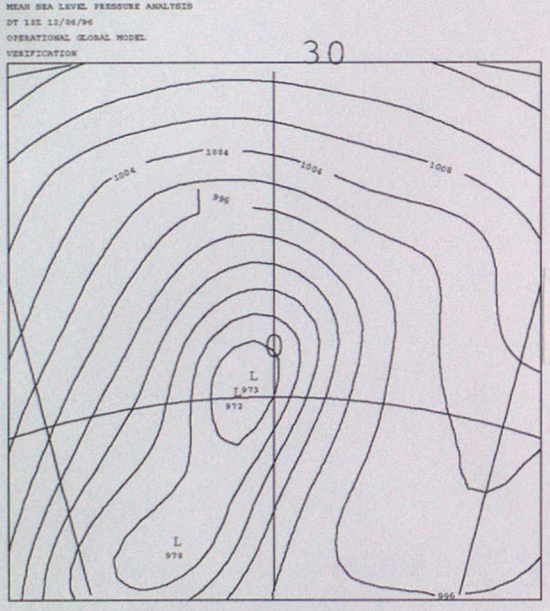
FIGURE 3.9



a

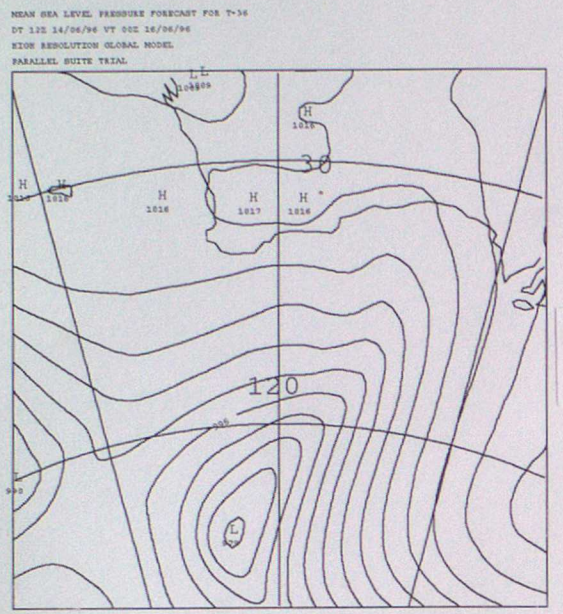


b

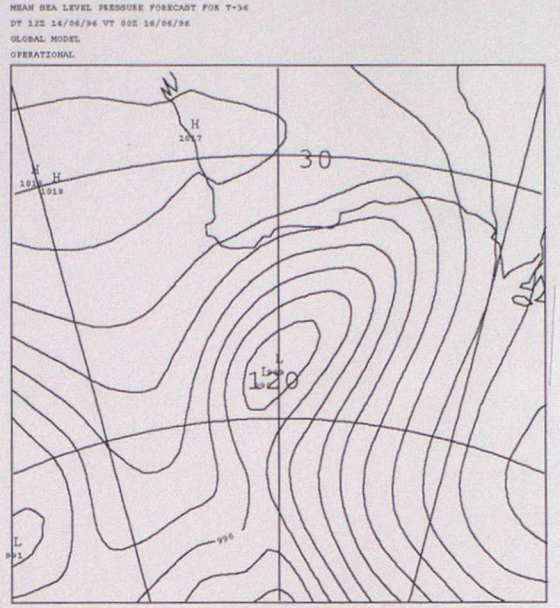


c

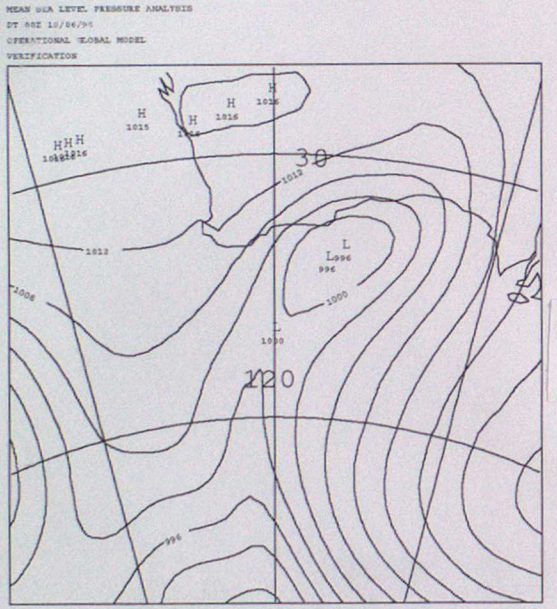
FIGURE 3.10



a

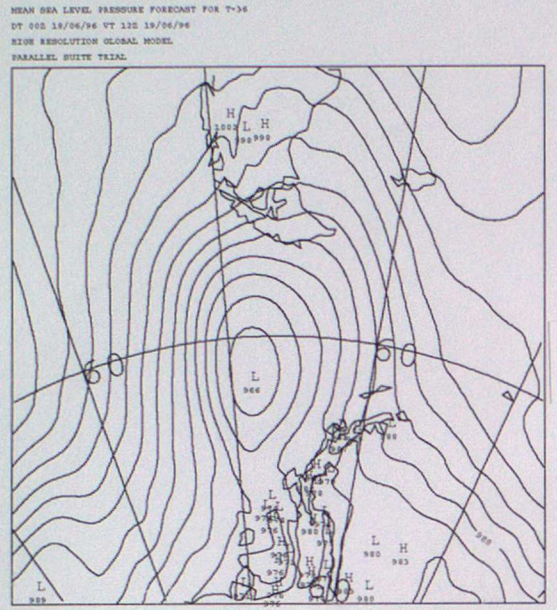


b

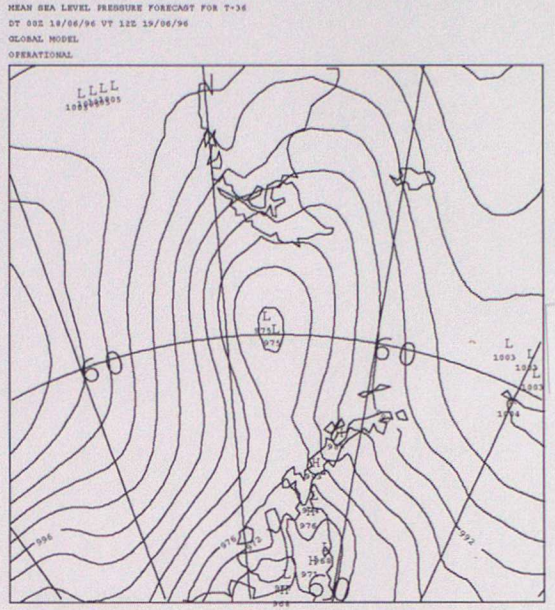


c

FIGURE 3.11



a



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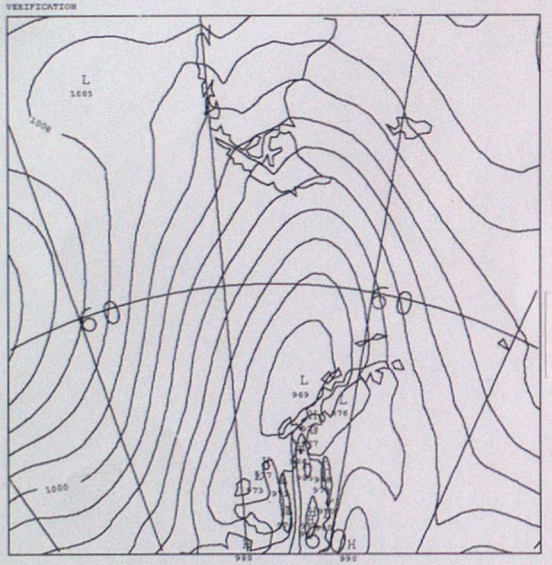
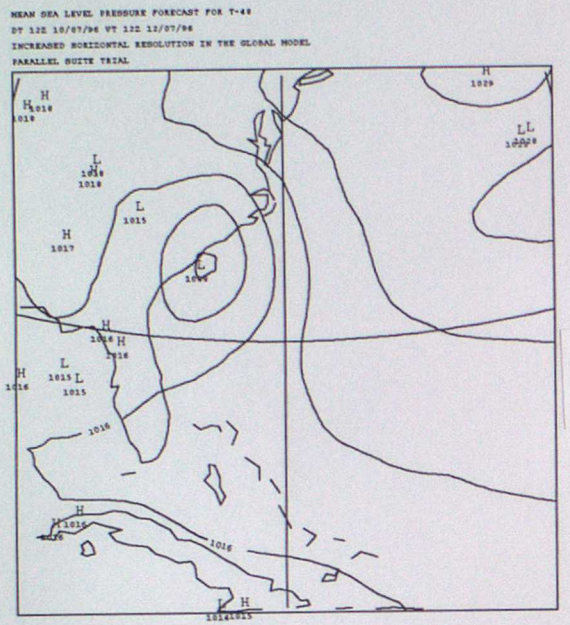


c

FIGURE 3.12



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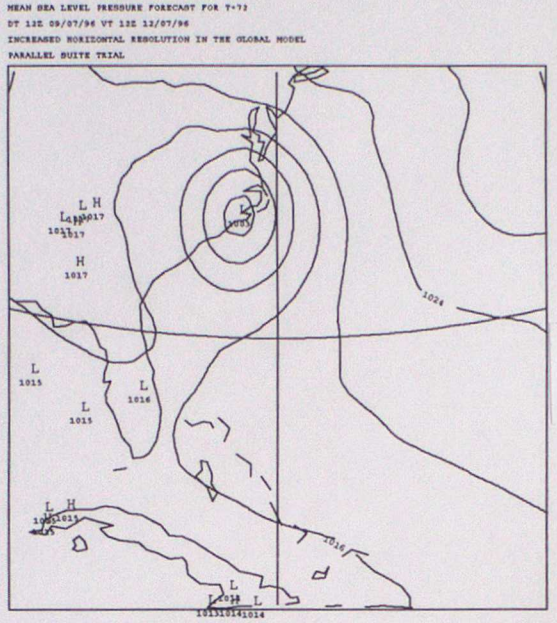

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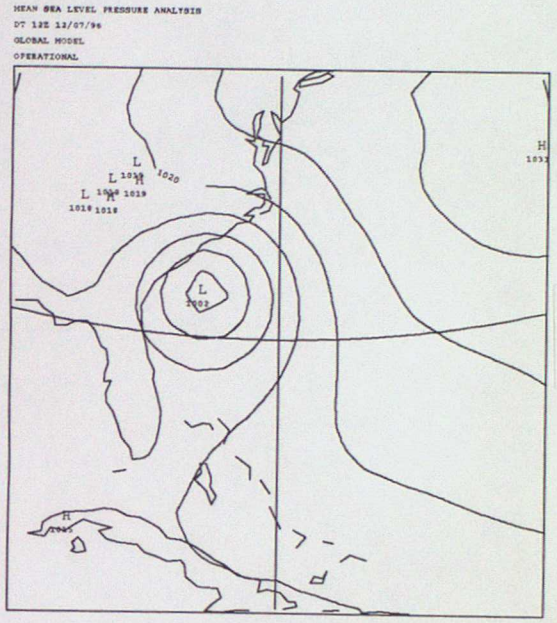
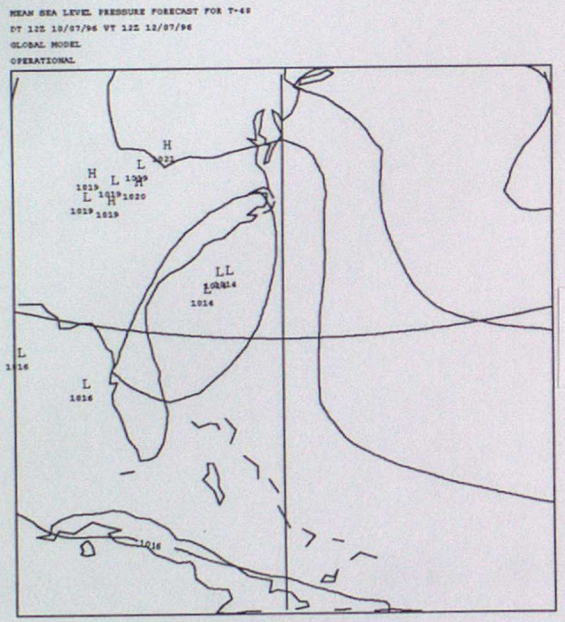
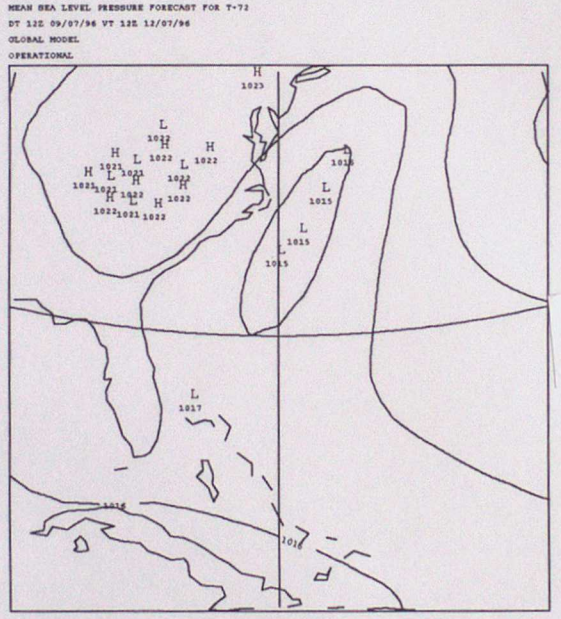


e

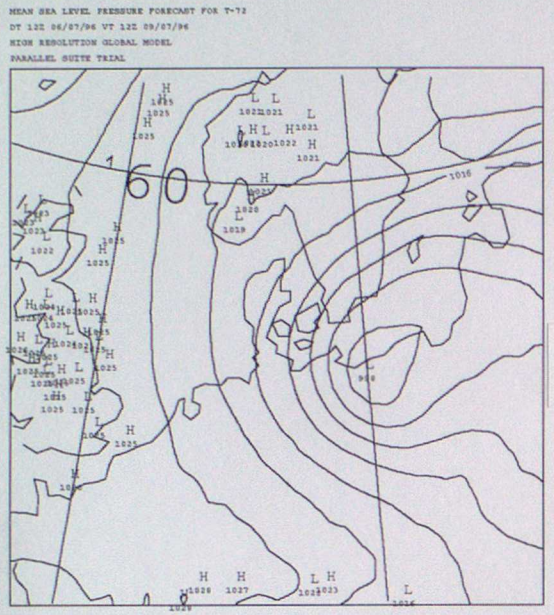


c

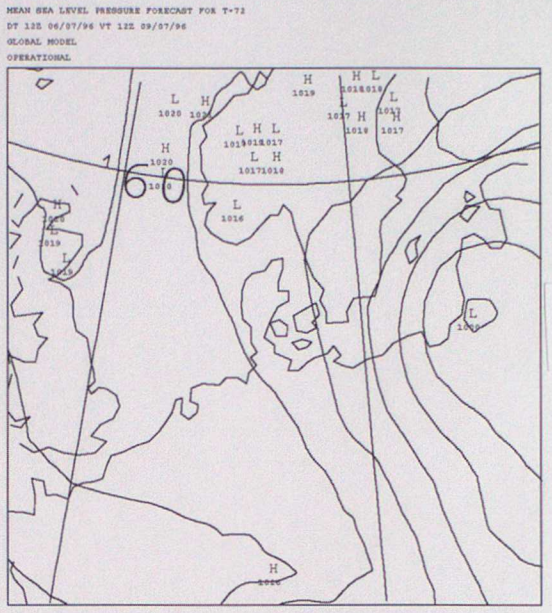


d

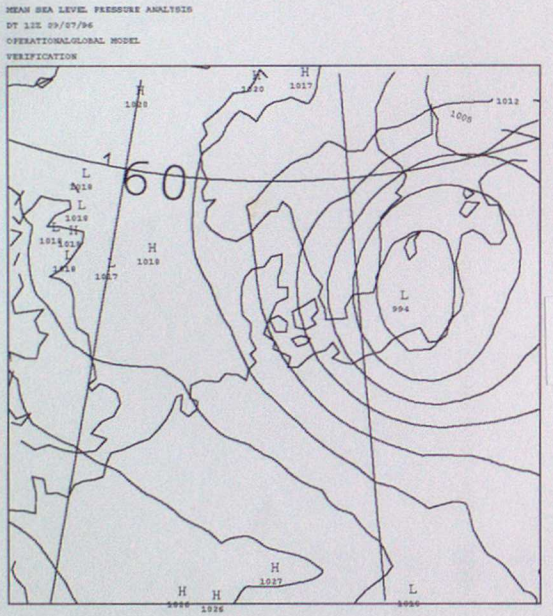
FIGURE 3.13



a

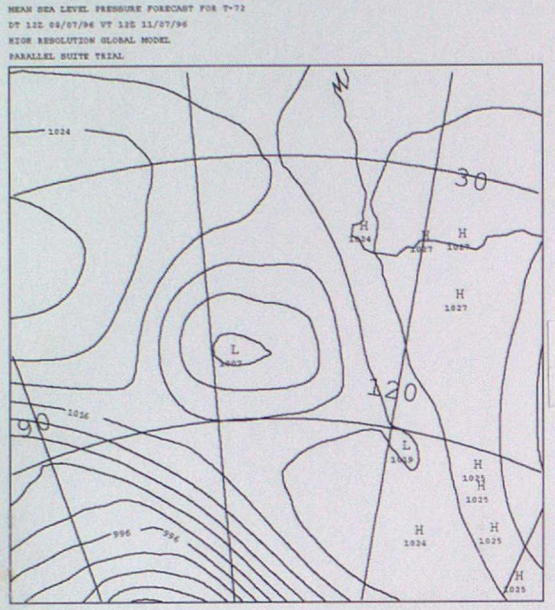


b

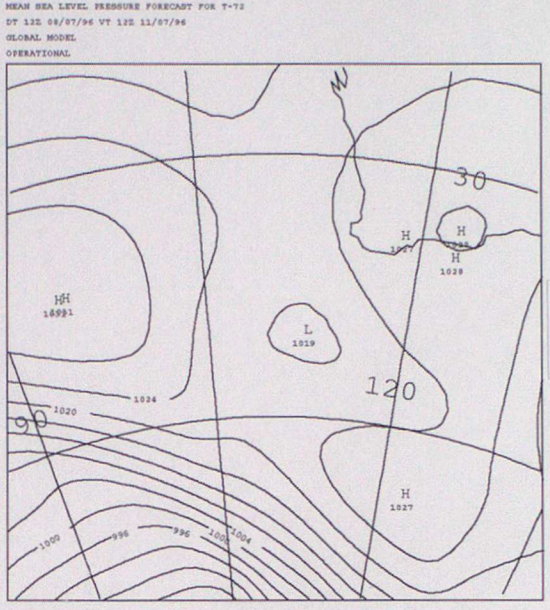


c

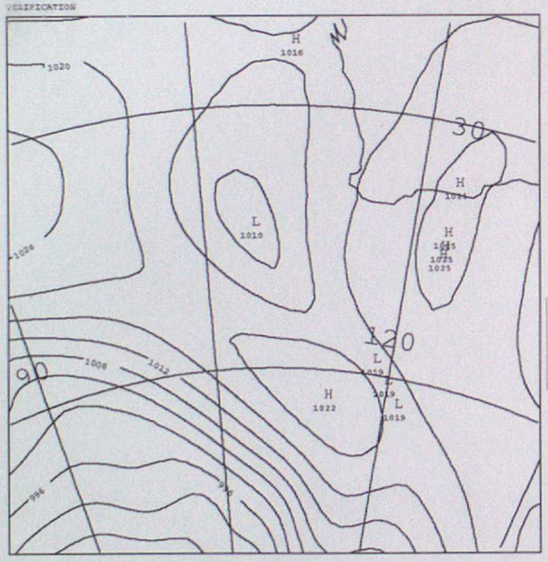
FIGURE 3.14



a



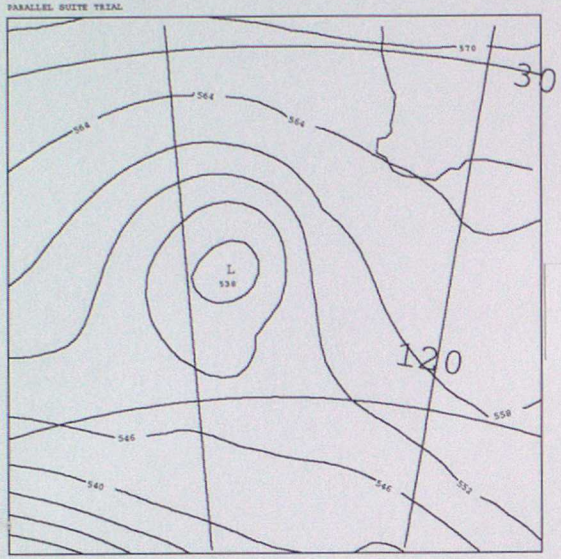
b



c

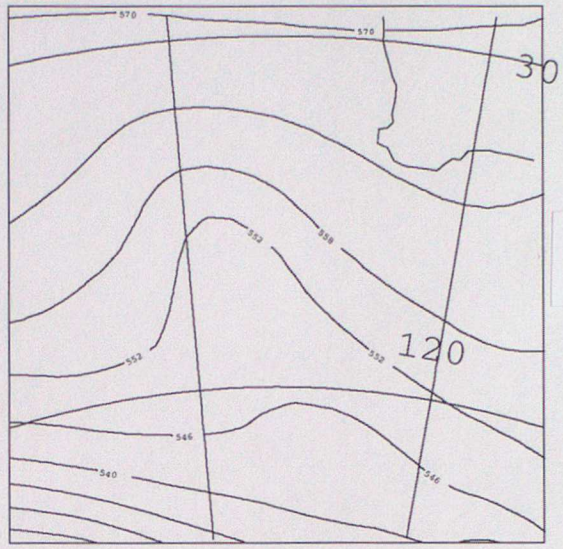
FIGURE 3.15

500hPa HEIGHT FORECAST FOR T+72
DT 12Z 08/07/96 VT 12Z 11/07/96
HIGH RESOLUTION GLOBAL MODEL
PARALLEL SUITE TRIAL



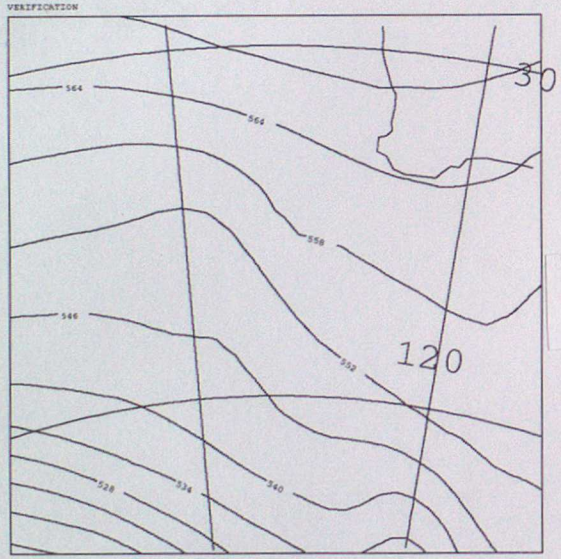
a

500hPa HEIGHT FORECAST FOR T+72
DT 12Z 08/07/96 VT 12Z 11/07/96
GLOBAL MODEL
OPERATIONAL



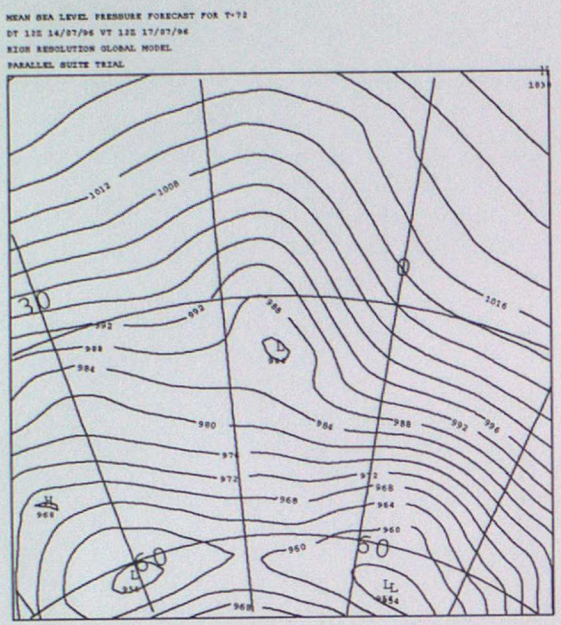
b

500hPa HEIGHT ANALYSIS
DT 12Z 11/07/96
OPERATIONAL GLOBAL MODEL
VERIFICATION

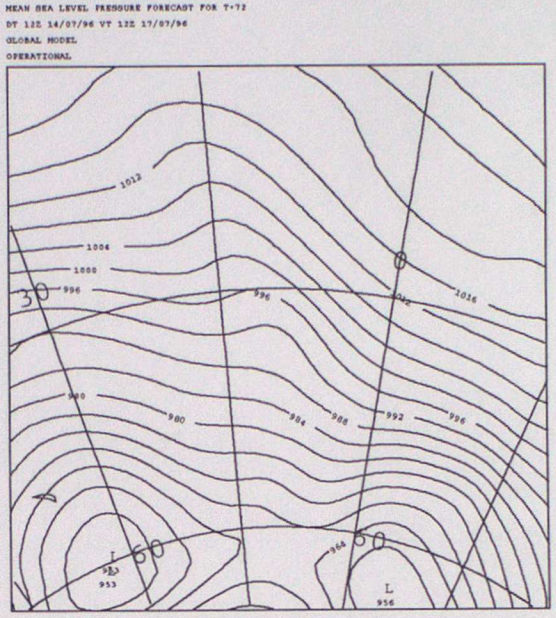


c

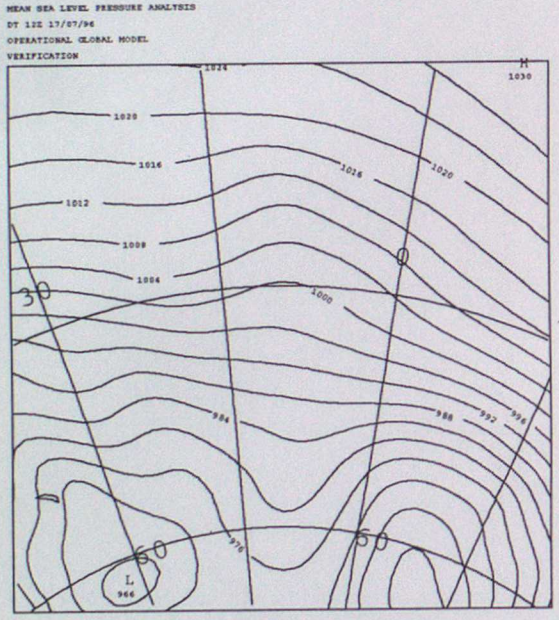
FIGURE 3.16



a

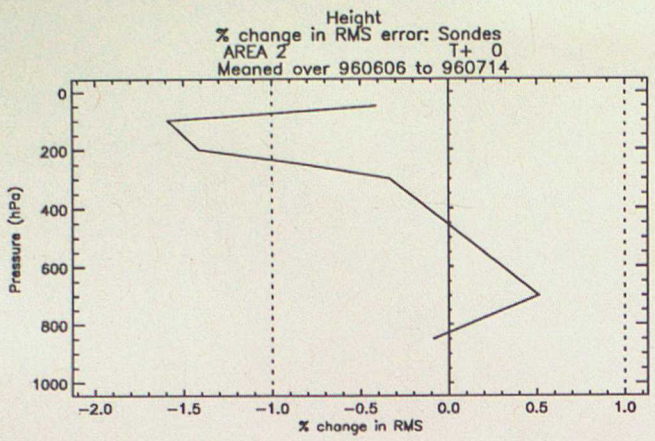


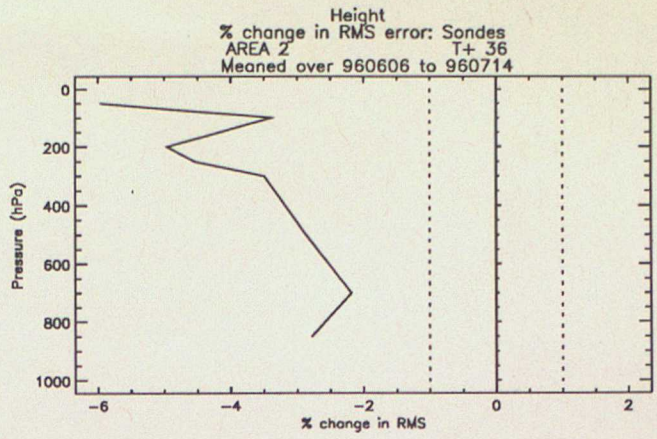
b

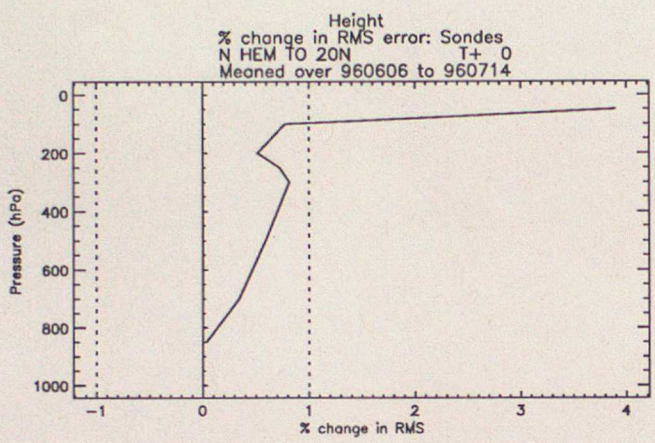


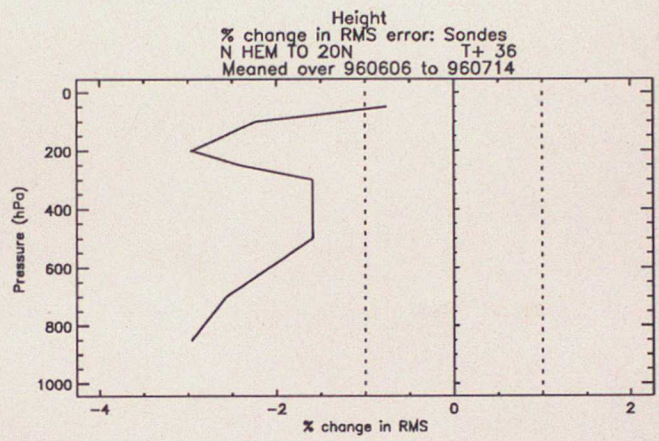
c

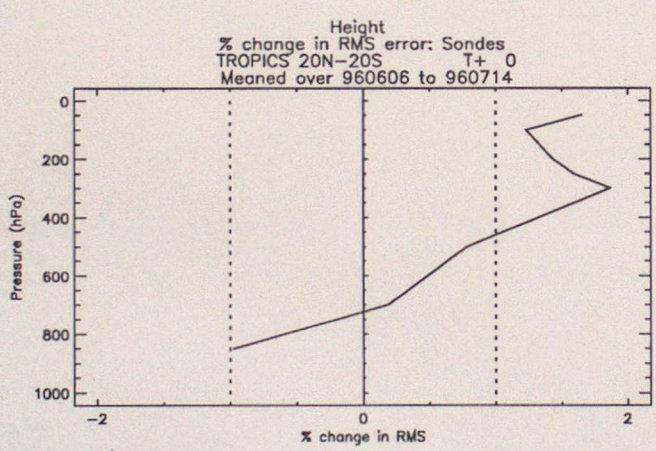
FIGURE 3.17

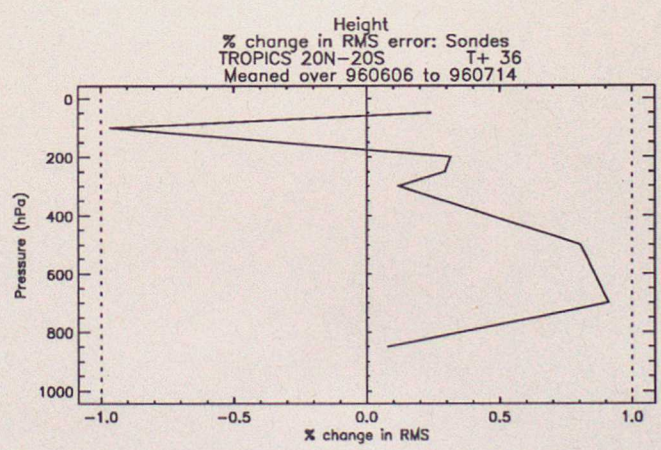

Height
% change in RMS error: Sondes
AREA 2 T+ 0
Meaned over 960606 to 960714
Pressure (hPa)
% change in RMS

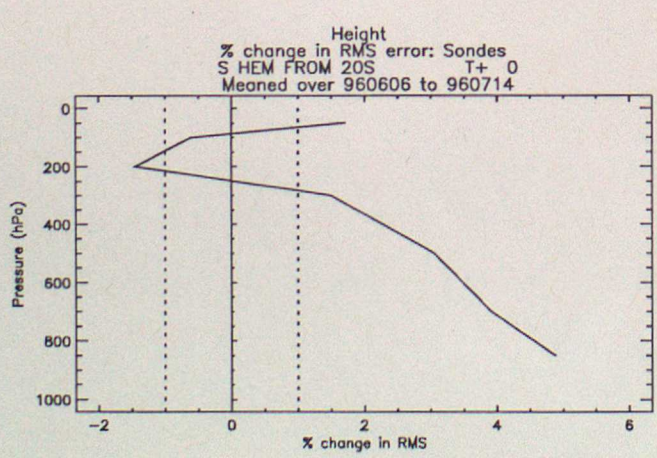

Height
% change in RMS error: Sondes
AREA 2 T+ 36
Meaned over 960606 to 960714
Pressure (hPa)
% change in RMS


Height
% change in RMS error: Sondes
N HEM TO 20N T+ 0
Meaned over 960606 to 960714
Pressure (hPa)
% change in RMS


Height
% change in RMS error: Sondes
N HEM TO 20N T+ 36
Meaned over 960606 to 960714
Pressure (hPa)
% change in RMS


Height
% change in RMS error: Sondes
TROPICS 20N-20S T+ 0
Meaned over 960606 to 960714
Pressure (hPa)
% change in RMS


Height
% change in RMS error: Sondes
TROPICS 20N-20S T+ 36
Meaned over 960606 to 960714
Pressure (hPa)
% change in RMS


Height
% change in RMS error: Sondes
S HEM FROM 20S T+ 0
Meaned over 960606 to 960714
Pressure (hPa)
% change in RMS

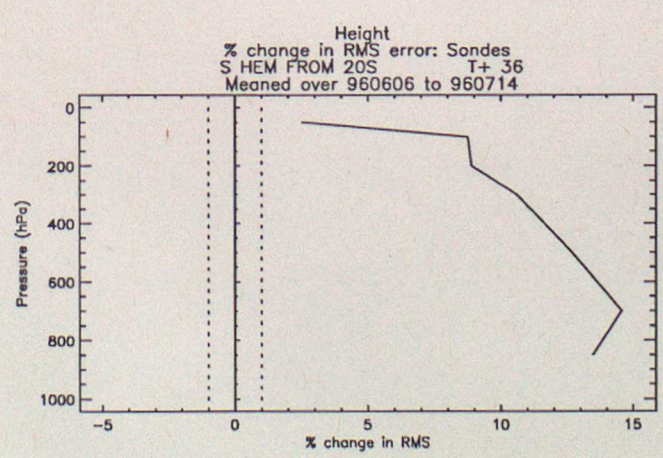

Height
% change in RMS error: Sondes
S HEM FROM 20S T+ 36
Meaned over 960606 to 960714
Pressure (hPa)
% change in RMS

FIGURE 4. 1

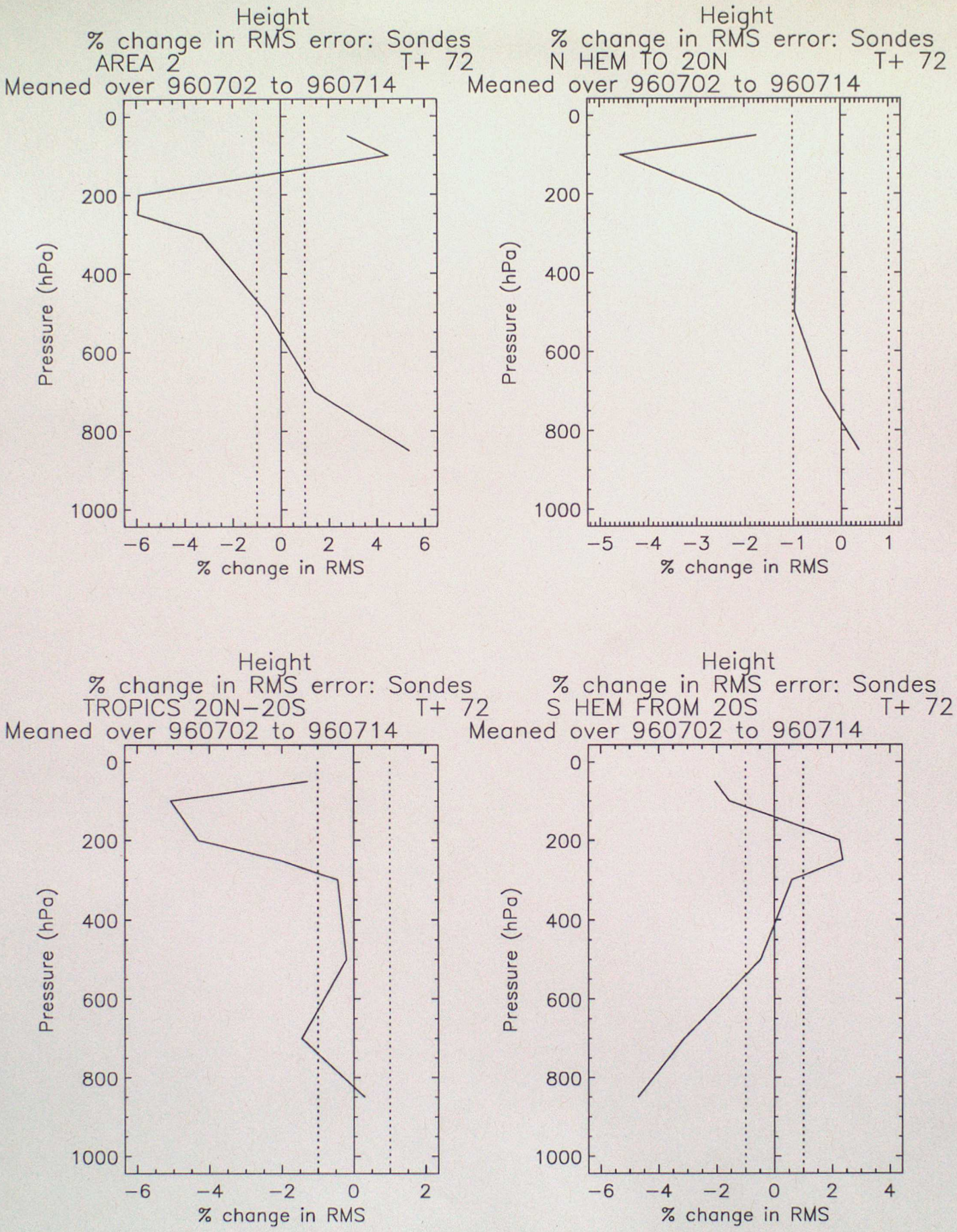

Height
% change in RMS error: Sondes
AREA 2 T+ 72
Meaned over 960702 to 960714
Pressure (hPa)
% change in RMS
Height
% change in RMS error: Sondes
N HEM TO 20N T+ 72
Meaned over 960702 to 960714
Pressure (hPa)
% change in RMS
Height
% change in RMS error: Sondes
TROPICS 20N-20S T+ 72
Meaned over 960702 to 960714
Pressure (hPa)
% change in RMS
Height
% change in RMS error: Sondes
S HEM FROM 20S T+ 72
Meaned over 960702 to 960714
Pressure (hPa)
% change in RMS

FIGURE 4. 2

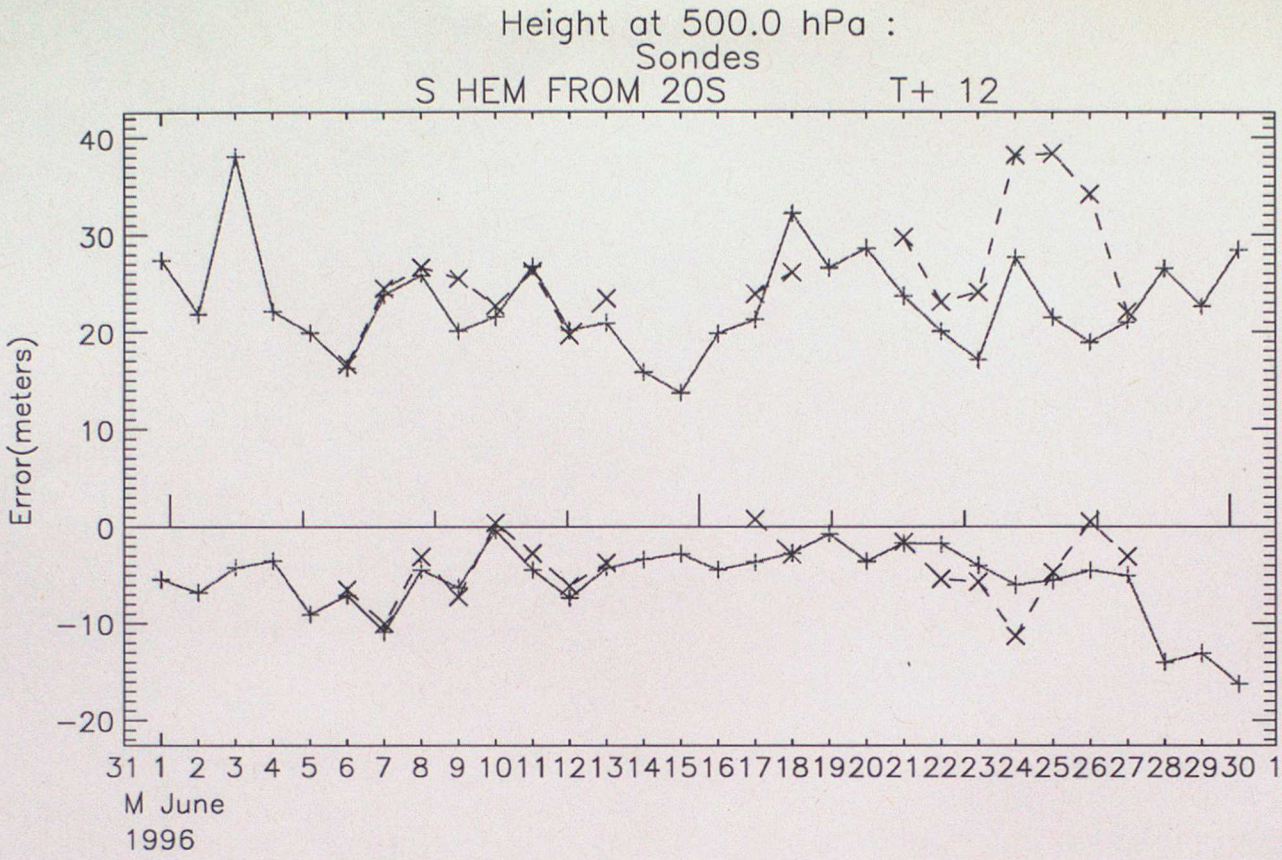
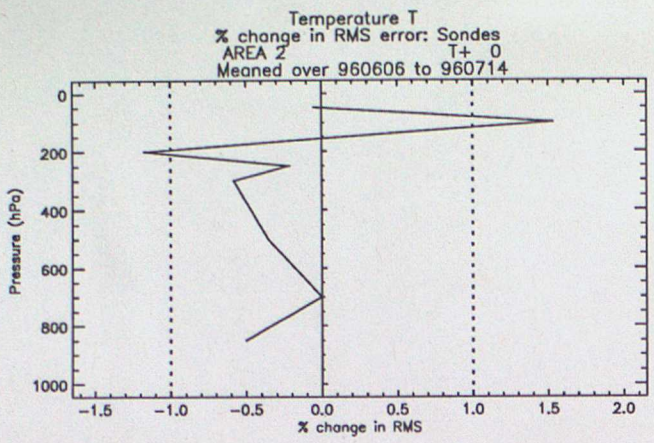
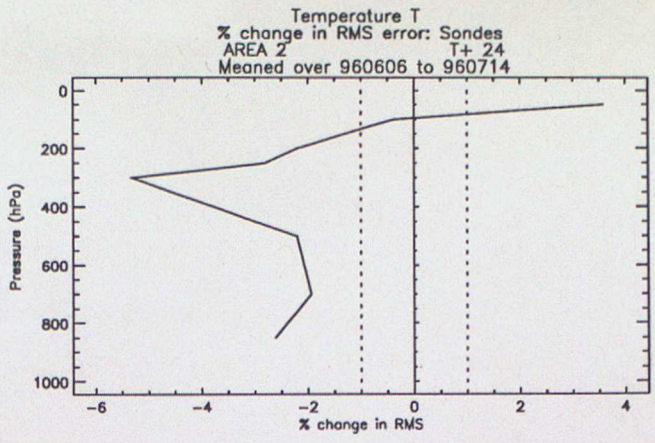
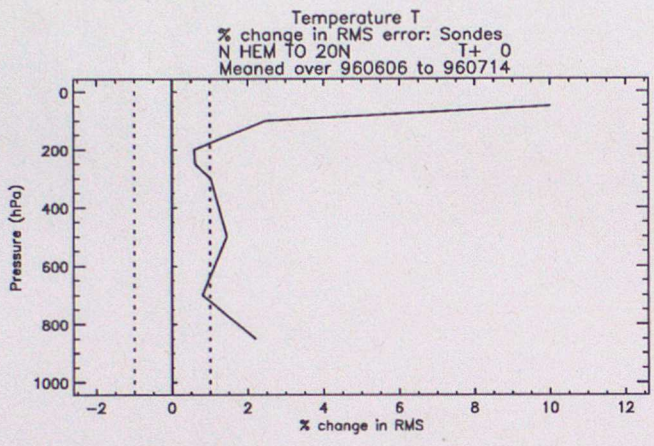
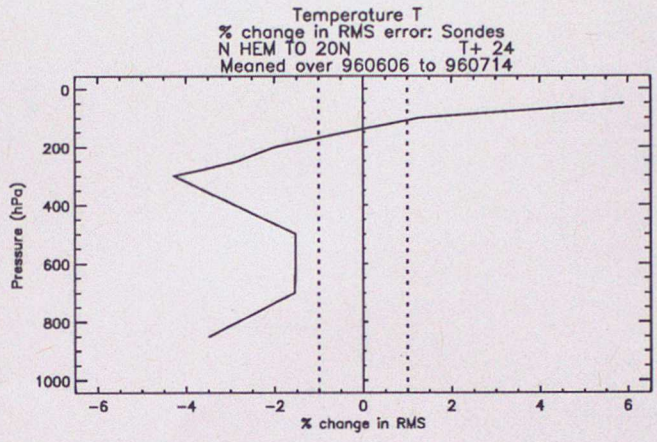

Height at 500.0 hPa :
Sondes
S HEM FROM 20S
T+ 12
Error(meters)
40
30
20
10
0
−10
−20
31 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 1
M June
1996

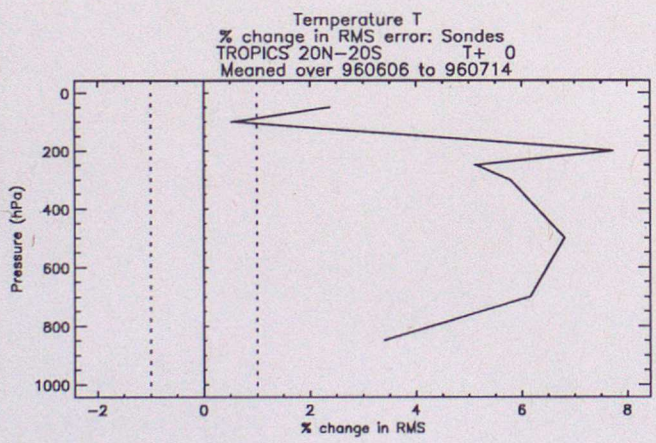
FIGURE 4. 3

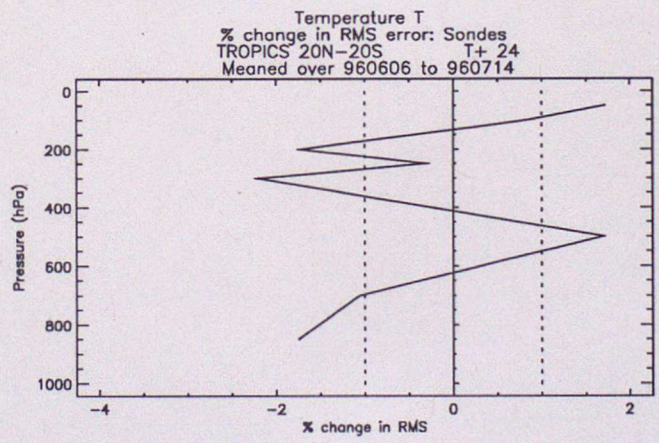

Temperature T
% change in RMS error: Sondes
AREA 2 T+ 0
Meaned over 960606 to 960714
Pressure (hPa)
% change in RMS

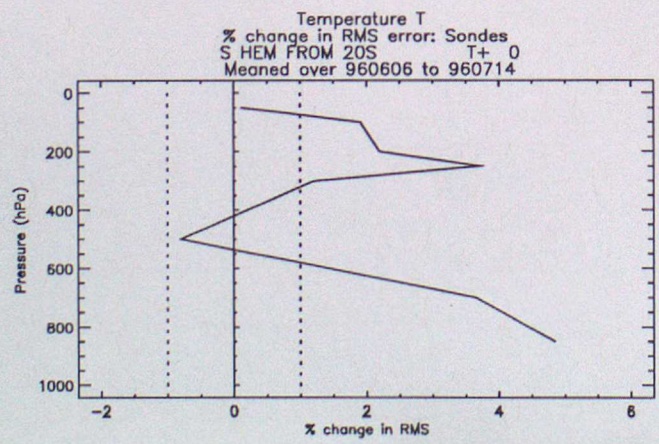

Temperature T
% change in RMS error: Sondes
AREA 2 T+ 24
Meaned over 960606 to 960714
Pressure (hPa)
% change in RMS


Temperature T
% change in RMS error: Sondes
N HEM TO 20N T+ 0
Meaned over 960606 to 960714
Pressure (hPa)
% change in RMS


Temperature T
% change in RMS error: Sondes
N HEM TO 20N T+ 24
Meaned over 960606 to 960714
Pressure (hPa)
% change in RMS


Temperature T
% change in RMS error: Sondes
TROPICS 20N-20S T+ 0
Meaned over 960606 to 960714
Pressure (hPa)
% change in RMS


Temperature T
% change in RMS error: Sondes
TROPICS 20N-20S T+ 24
Meaned over 960606 to 960714
Pressure (hPa)
% change in RMS


Temperature T
% change in RMS error: Sondes
S HEM FROM 20S T+ 0
Meaned over 960606 to 960714
Pressure (hPa)
% change in RMS

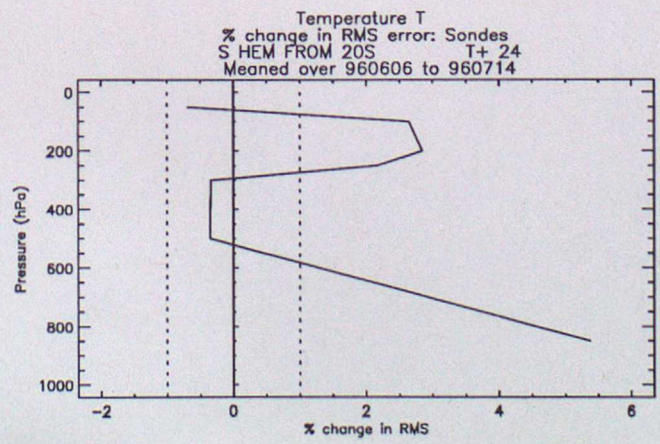

Temperature T
% change in RMS error: Sondes
S HEM FROM 20S T+ 24
Meaned over 960606 to 960714
Pressure (hPa)
% change in RMS

FIGURE 4. 4

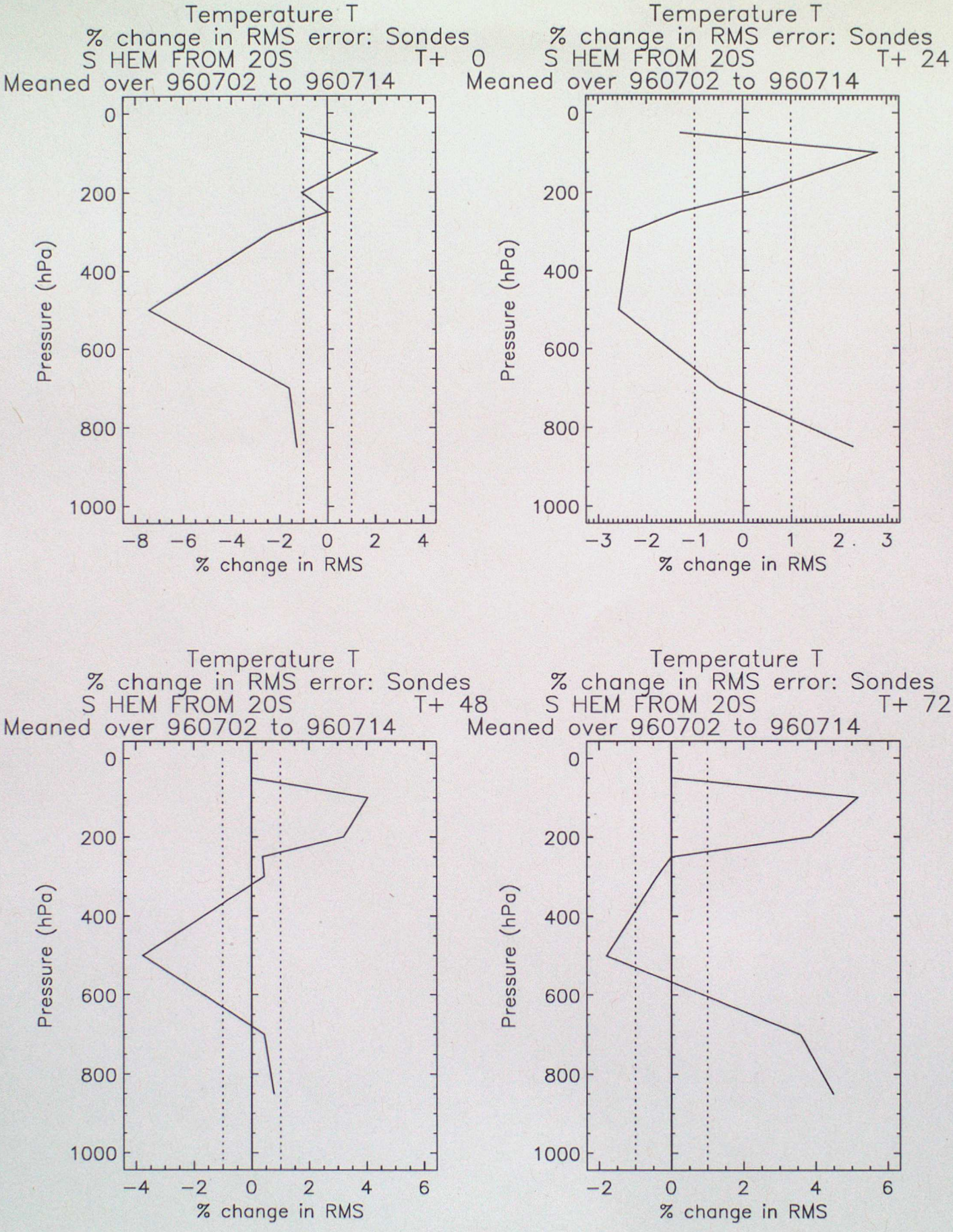
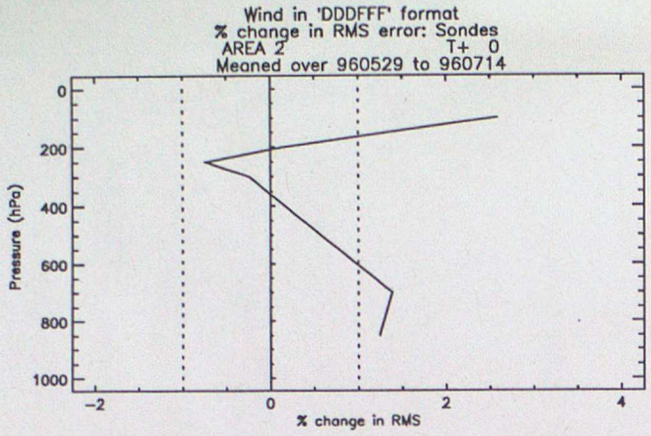
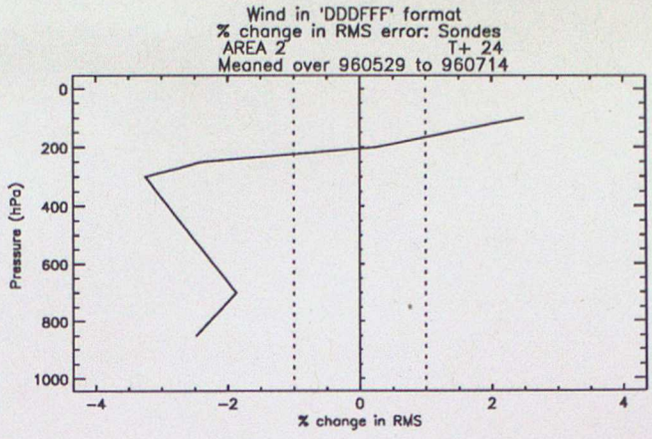
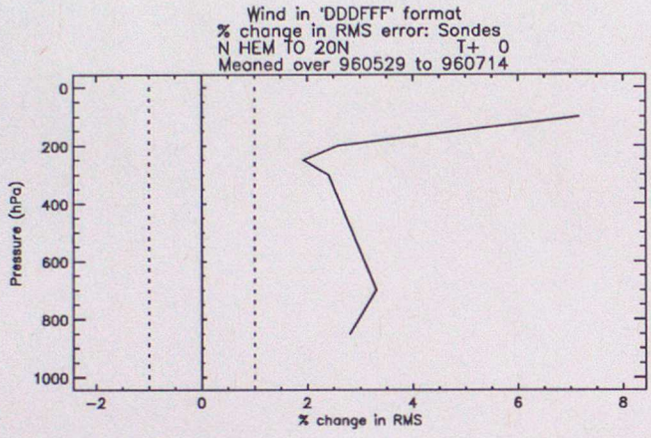
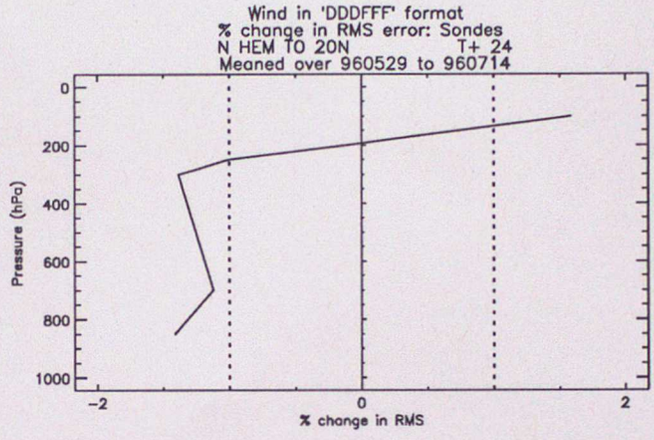

Temperature T
% change in RMS error: Sondes
S HEM FROM 20S T+ 0
Meaned over 960702 to 960714
Pressure (hPa)
0
200
400
600
800
1000
−8 −6 −4 −2 0 2 4
% change in RMS
Temperature T
% change in RMS error: Sondes
S HEM FROM 20S T+ 24
Meaned over 960702 to 960714
Pressure (hPa)
0
200
400
600
800
1000
−3 −2 −1 0 1 2 3
% change in RMS
Temperature T
% change in RMS error: Sondes
S HEM FROM 20S T+ 48
Meaned over 960702 to 960714
Pressure (hPa)
0
200
400
600
800
1000
−4 −2 0 2 4 6
% change in RMS
Temperature T
% change in RMS error: Sondes
S HEM FROM 20S T+ 72
Meaned over 960702 to 960714
Pressure (hPa)
0
200
400
600
800
1000
−2 0 2 4 6
% change in RMS

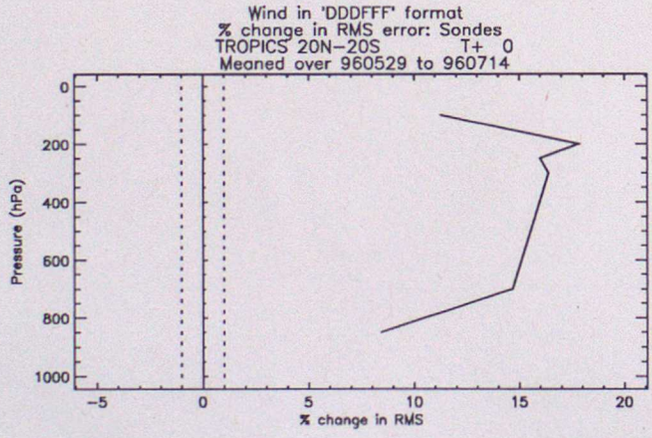
FIGURE 4. 5

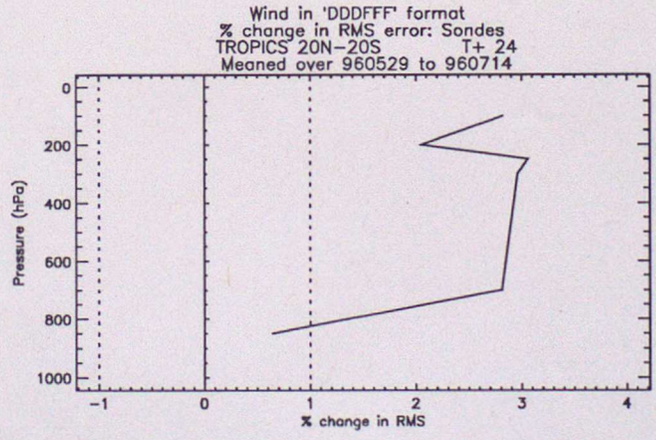

Wind in 'DDDFFF' format
% change in RMS error: Sondes
AREA 2 T+ 0
Meaned over 960529 to 960714
Pressure (hPa)
% change in RMS

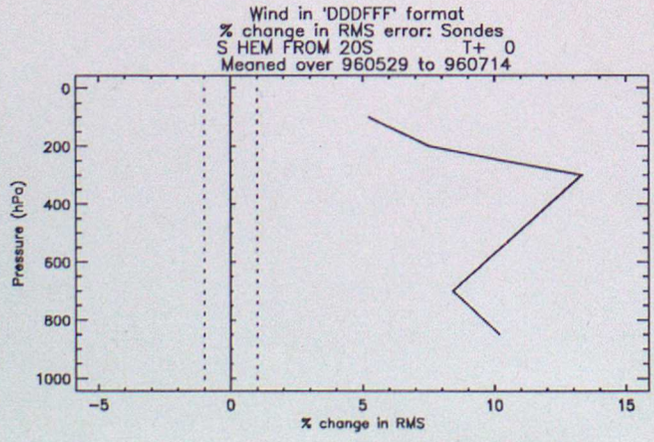

Wind in 'DDDFFF' format
% change in RMS error: Sondes
AREA 2 T+ 24
Meaned over 960529 to 960714
Pressure (hPa)
% change in RMS


Wind in 'DDDFFF' format
% change in RMS error: Sondes
N HEM TO 20N T+ 0
Meaned over 960529 to 960714
Pressure (hPa)
% change in RMS


Wind in 'DDDFFF' format
% change in RMS error: Sondes
N HEM TO 20N T+ 24
Meaned over 960529 to 960714
Pressure (hPa)
% change in RMS


Wind in 'DDDFFF' format
% change in RMS error: Sondes
TROPICS 20N-20S T+ 0
Meaned over 960529 to 960714
Pressure (hPa)
% change in RMS


Wind in 'DDDFFF' format
% change in RMS error: Sondes
TROPICS 20N-20S T+ 24
Meaned over 960529 to 960714
Pressure (hPa)
% change in RMS


Wind in 'DDDFFF' format
% change in RMS error: Sondes
S HEM FROM 20S T+ 0
Meaned over 960529 to 960714
Pressure (hPa)
% change in RMS

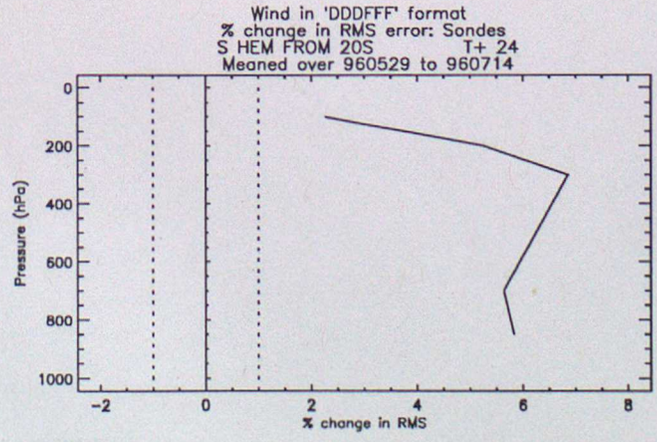

Wind in 'DDDFFF' format
% change in RMS error: Sondes
S HEM FROM 20S T+ 24
Meaned over 960529 to 960714
Pressure (hPa)
% change in RMS

FIGURE 4. 6

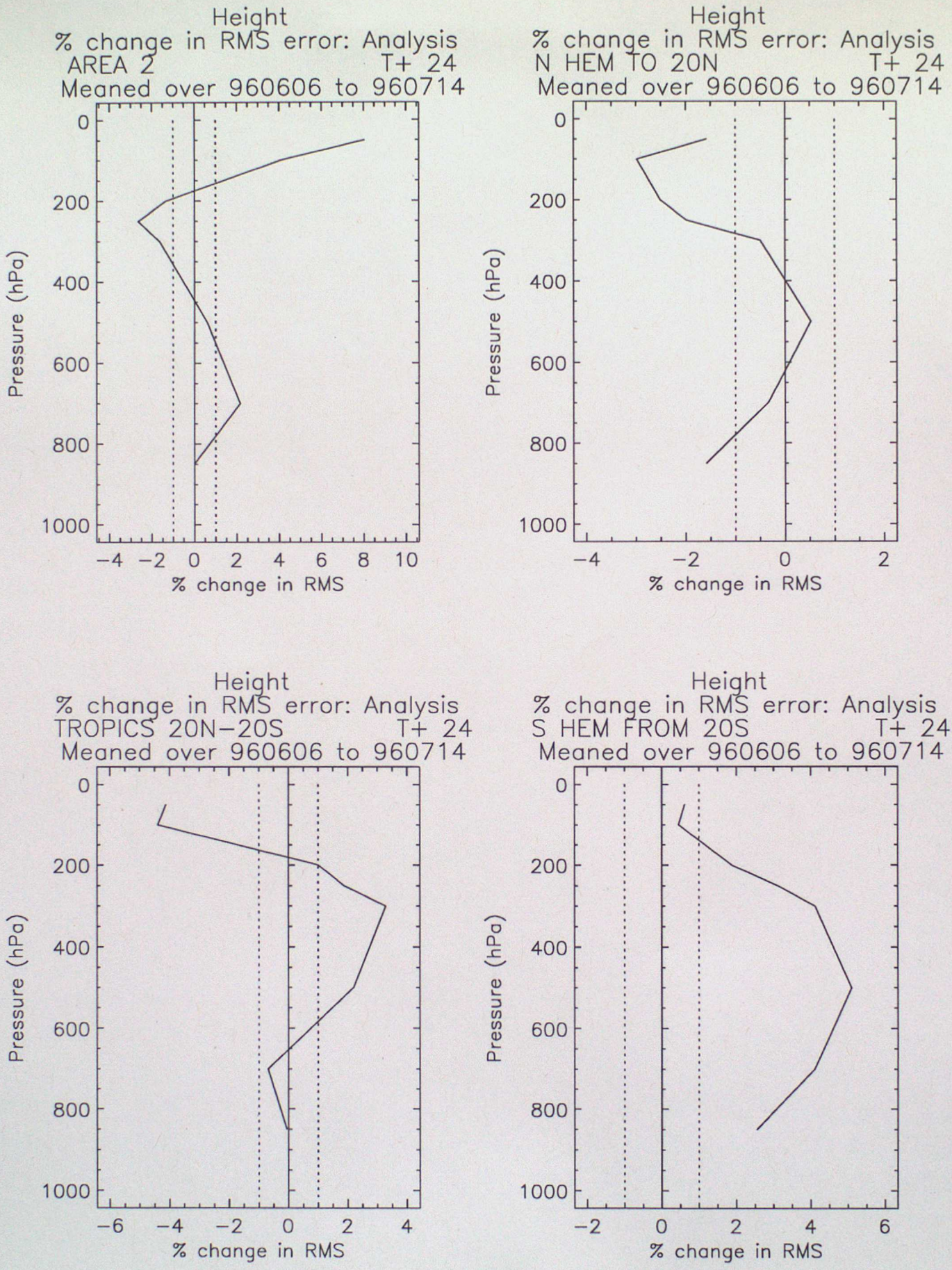

Height
% change in RMS error: Analysis
AREA 2 T+ 24
Meaned over 960606 to 960714
Pressure (hPa)
0
200
400
600
800
1000
−4 −2 0 2 4 6 8 10
% change in RMS
Height
% change in RMS error: Analysis
N HEM TO 20N T+ 24
Meaned over 960606 to 960714
Pressure (hPa)
0
200
400
600
800
1000
−4 −2 0 2
% change in RMS
Height
% change in RMS error: Analysis
TROPICS 20N−20S T+ 24
Meaned over 960606 to 960714
Pressure (hPa)
0
200
400
600
800
1000
−6 −4 −2 0 2 4
% change in RMS
Height
% change in RMS error: Analysis
S HEM FROM 20S T+ 24
Meaned over 960606 to 960714
Pressure (hPa)
0
200
400
600
800
1000
−2 0 2 4 6
% change in RMS

FIGURE 4. 7

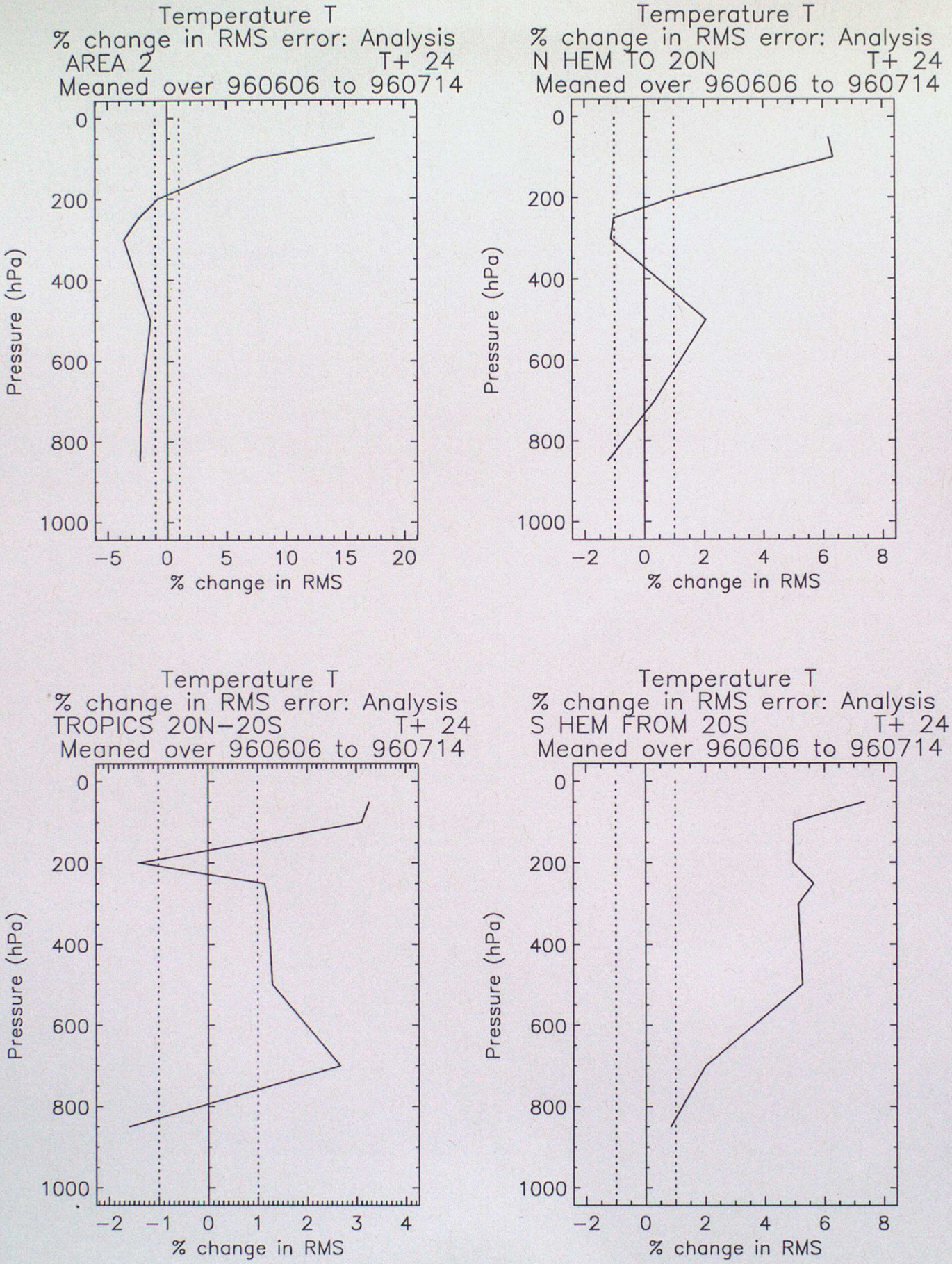

Temperature T
% change in RMS error: Analysis
AREA 2 T+ 24
Meaned over 960606 to 960714
Pressure (hPa)
0
200
400
600
800
1000
−5 0 5 10 15 20
% change in RMS
Temperature T
% change in RMS error: Analysis
N HEM TO 20N T+ 24
Meaned over 960606 to 960714
Pressure (hPa)
0
200
400
600
800
1000
−2 0 2 4 6 8
% change in RMS
Temperature T
% change in RMS error: Analysis
TROPICS 20N−20S T+ 24
Meaned over 960606 to 960714
Pressure (hPa)
0
200
400
600
800
1000
−2 −1 0 1 2 3 4
% change in RMS
Temperature T
% change in RMS error: Analysis
S HEM FROM 20S T+ 24
Meaned over 960606 to 960714
Pressure (hPa)
0
200
400
600
800
1000
−2 0 2 4 6 8
% change in RMS

FIGURE 4. 8

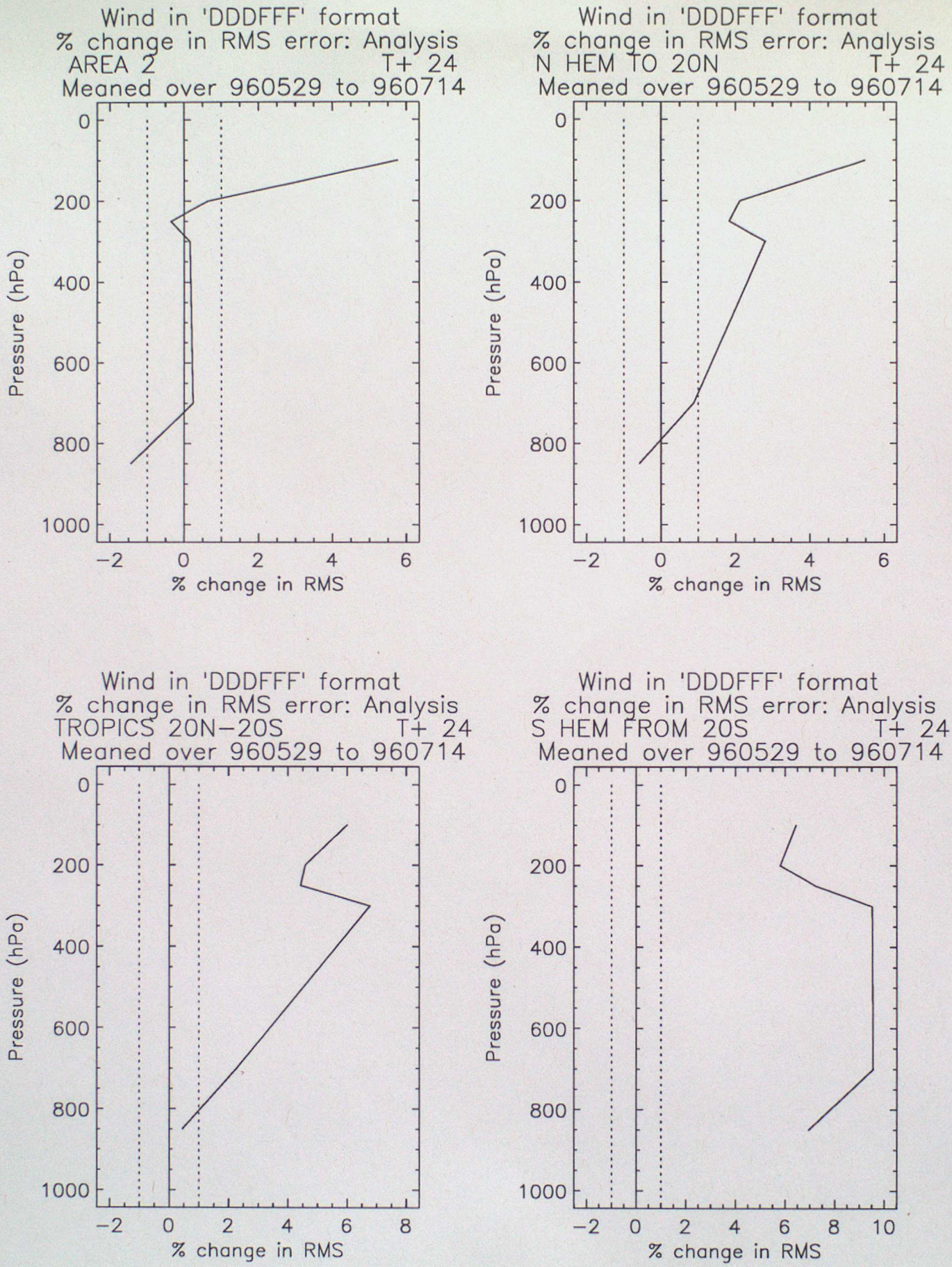
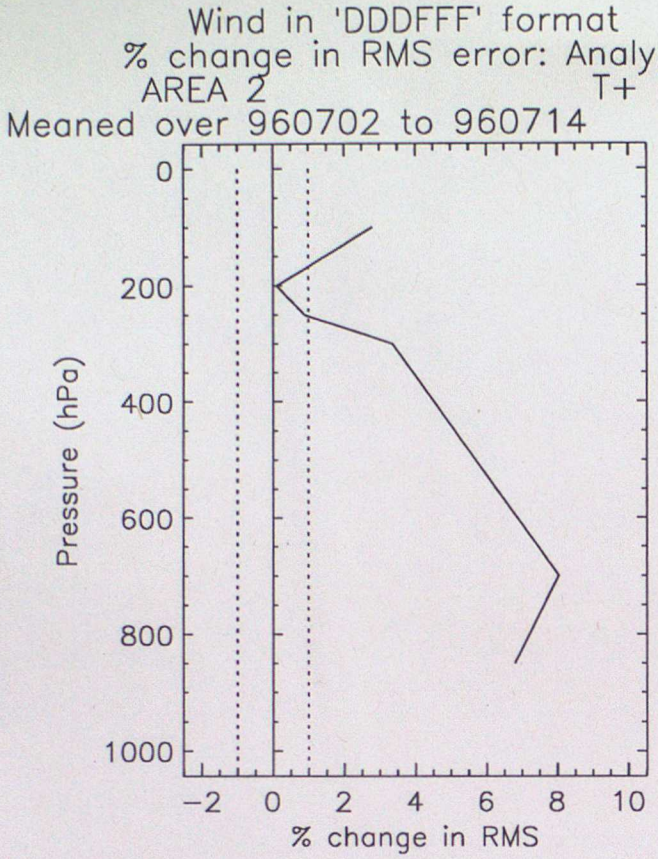
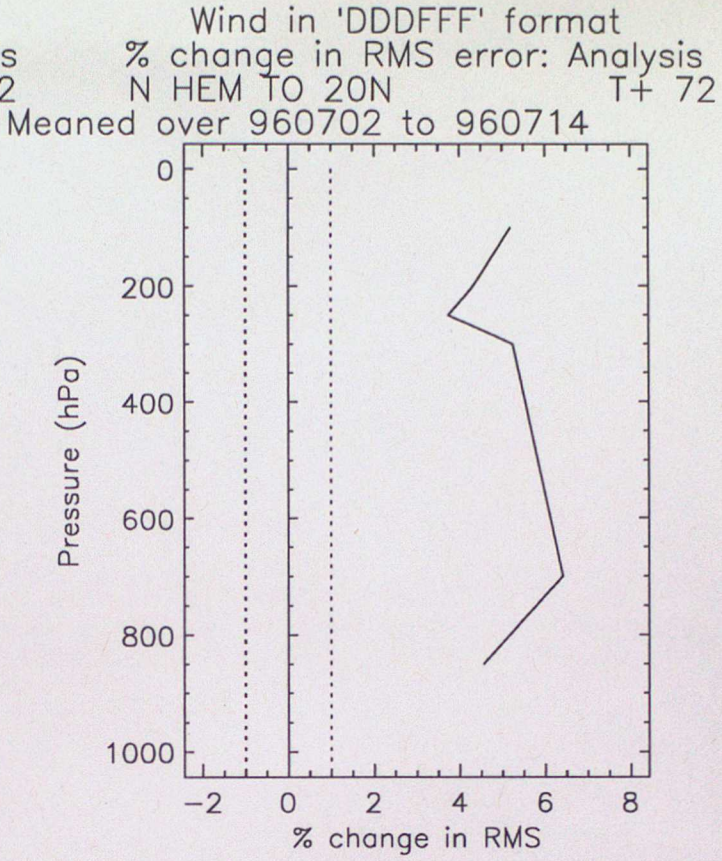
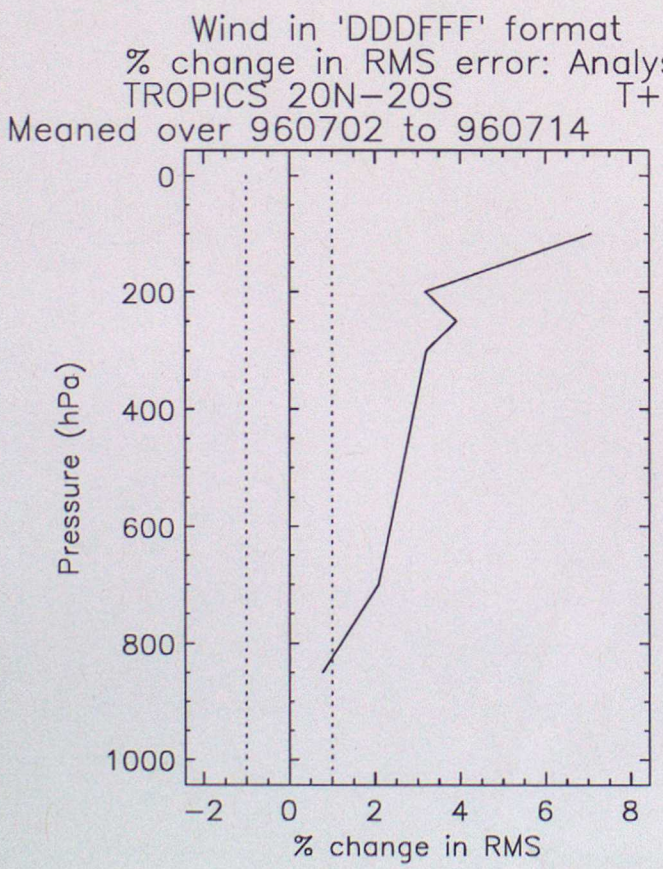

Wind in 'DDDFFF' format
% change in RMS error: Analysis
AREA 2 T+ 24
Meaned over 960529 to 960714
Pressure (hPa)
0
200
400
600
800
1000
−2
0
2
4
6
% change in RMS
Wind in 'DDDFFF' format
% change in RMS error: Analysis
N HEM TO 20N T+ 24
Meaned over 960529 to 960714
Pressure (hPa)
% change in RMS
Wind in 'DDDFFF' format
% change in RMS error: Analysis
TROPICS 20N−20S T+ 24
Meaned over 960529 to 960714
Pressure (hPa)
8
% change in RMS
Wind in 'DDDFFF' format
% change in RMS error: Analysis
S HEM FROM 20S T+ 24
Meaned over 960529 to 960714
Pressure (hPa)
10
% change in RMS

FIGURE 4. 9


Wind in 'DDDFFF' format
% change in RMS error: Analysis
AREA 2 T+ 72
Meaned over 960702 to 960714
Pressure (hPa)
0
200
400
600
800
1000
−2 0 2 4 6 8 10
% change in RMS


Wind in 'DDDFFF' format
% change in RMS error: Analysis
N HEM TO 20N T+ 72
Meaned over 960702 to 960714
Pressure (hPa)
0
200
400
600
800
1000
−2 0 2 4 6 8
% change in RMS


Wind in 'DDDFFF' format
% change in RMS error: Analysis
TROPICS 20N−20S T+ 72
Meaned over 960702 to 960714
Pressure (hPa)
0
200
400
600
800
1000
−2 0 2 4 6 8
% change in RMS

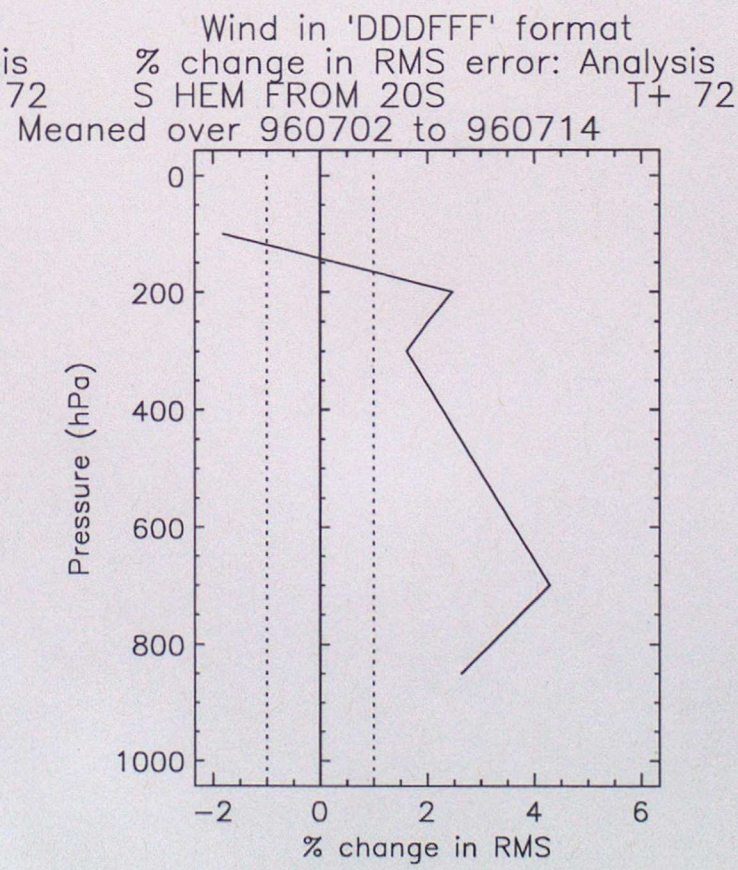
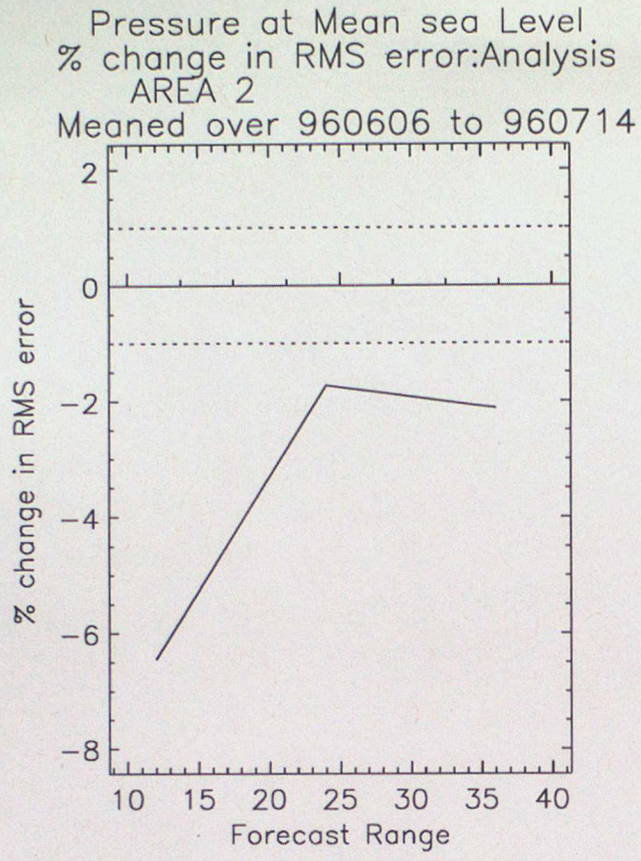
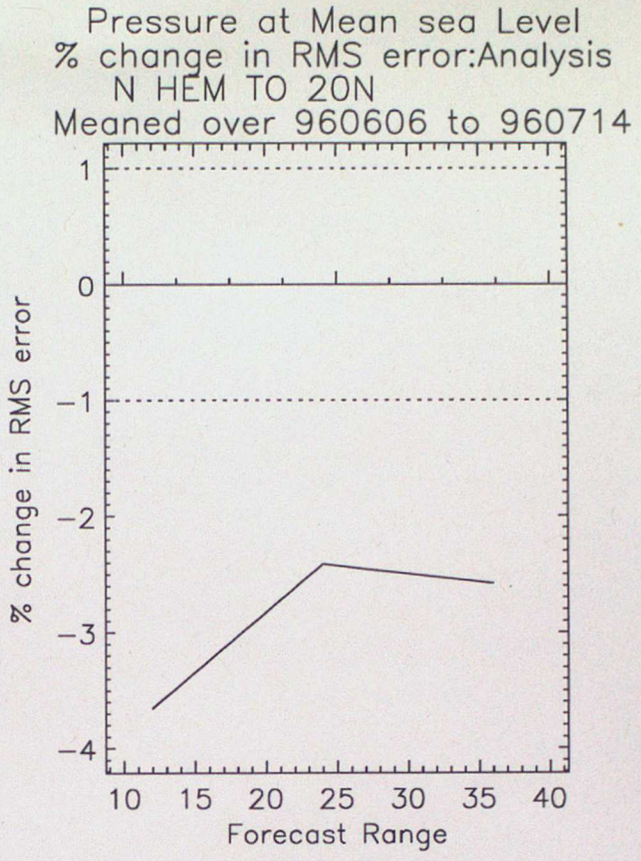
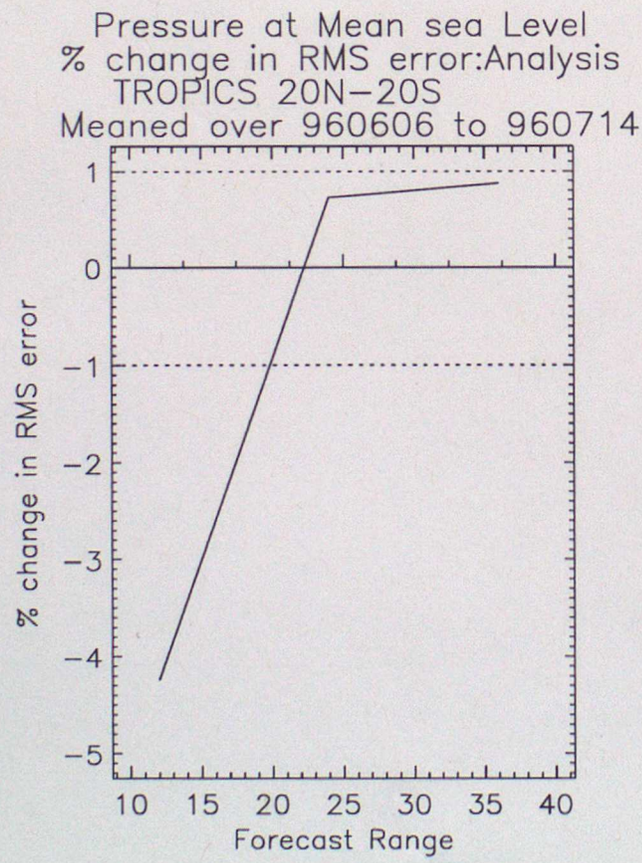

Wind in 'DDDFFF' format
% change in RMS error: Analysis
S HEM FROM 20S T+ 72
Meaned over 960702 to 960714
Pressure (hPa)
0
200
400
600
800
1000
−2 0 2 4 6
% change in RMS

FIGURE 4. 10


Pressure at Mean sea Level
% change in RMS error:Analysis
AREA 2
Meaned over 960606 to 960714
% change in RMS error
Forecast Range


Pressure at Mean sea Level
% change in RMS error:Analysis
N HEM TO 20N
Meaned over 960606 to 960714
% change in RMS error
Forecast Range


Pressure at Mean sea Level
% change in RMS error:Analysis
TROPICS 20N-20S
Meaned over 960606 to 960714
% change in RMS error
Forecast Range

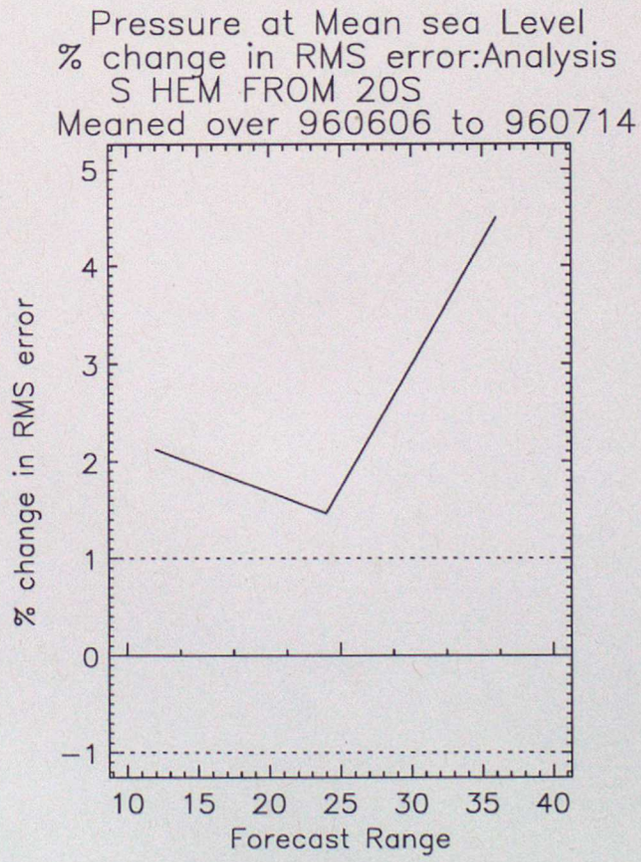
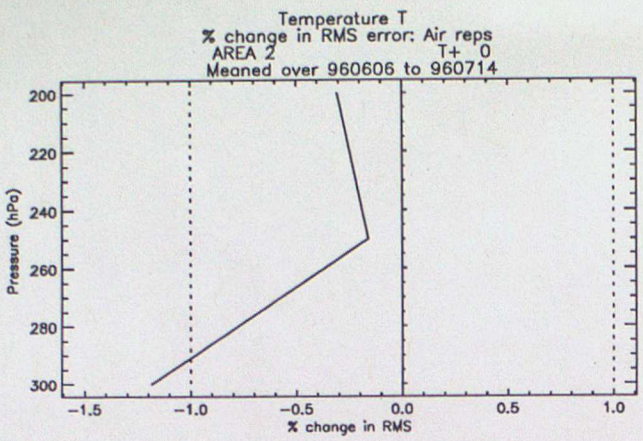
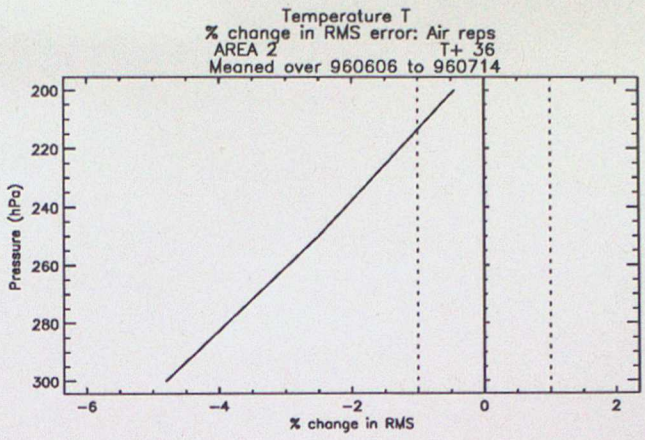
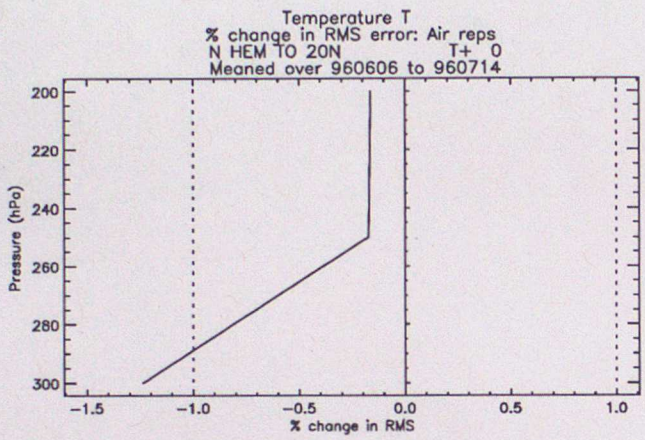
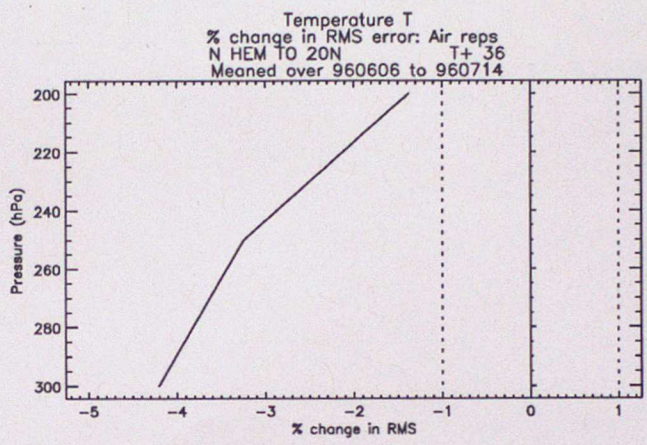

Pressure at Mean sea Level
% change in RMS error:Analysis
S HEM FROM 20S
Meaned over 960606 to 960714
% change in RMS error
Forecast Range

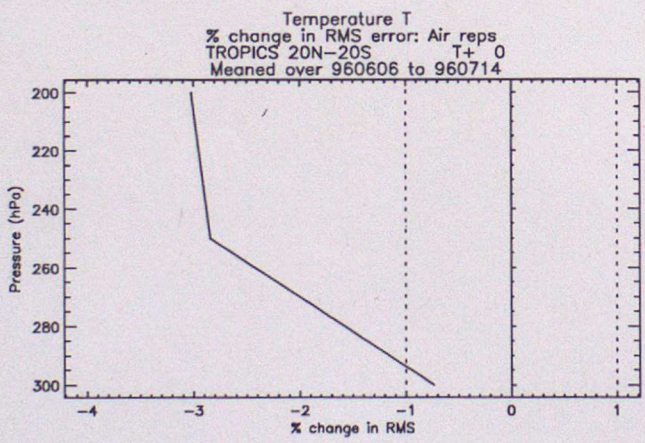
FIGURE 4. 11

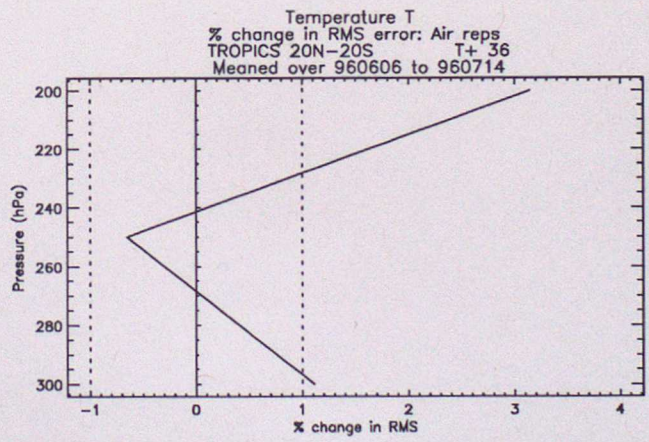

Temperature T
% change in RMS error: Air reps
AREA 2 T+ 0
Meaned over 960606 to 960714
Pressure (hPa)
% change in RMS

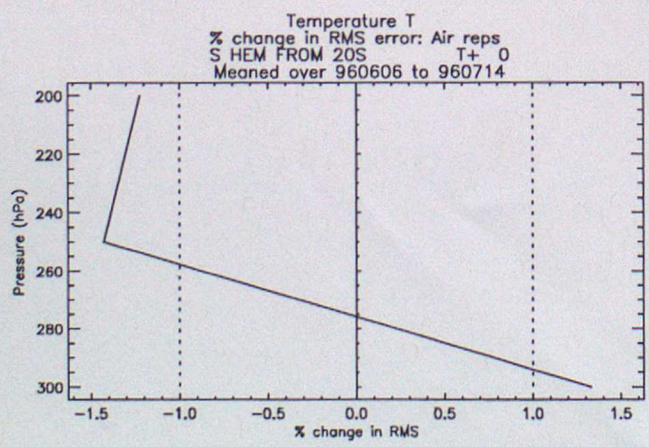

Temperature T
% change in RMS error: Air reps
AREA 2 T+ 36
Meaned over 960606 to 960714
Pressure (hPa)
% change in RMS


Temperature T
% change in RMS error: Air reps
N HEM TO 20N T+ 0
Meaned over 960606 to 960714
Pressure (hPa)
% change in RMS


Temperature T
% change in RMS error: Air reps
N HEM TO 20N T+ 36
Meaned over 960606 to 960714
Pressure (hPa)
% change in RMS


Temperature T
% change in RMS error: Air reps
TROPICS 20N-20S T+ 0
Meaned over 960606 to 960714
Pressure (hPa)
% change in RMS


Temperature T
% change in RMS error: Air reps
TROPICS 20N-20S T+ 36
Meaned over 960606 to 960714
Pressure (hPa)
% change in RMS


Temperature T
% change in RMS error: Air reps
S HEM FROM 20S T+ 0
Meaned over 960606 to 960714
Pressure (hPa)
% change in RMS

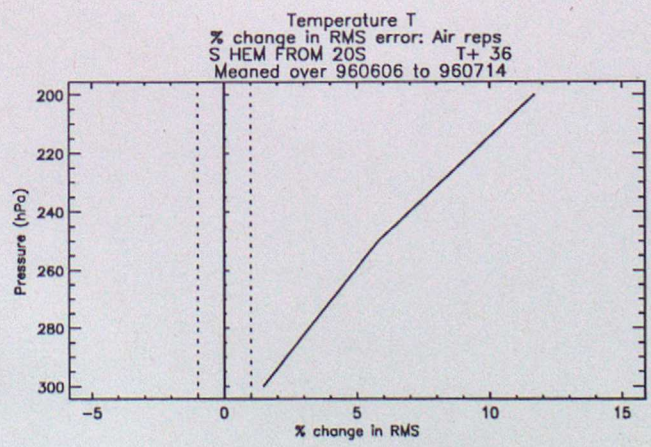
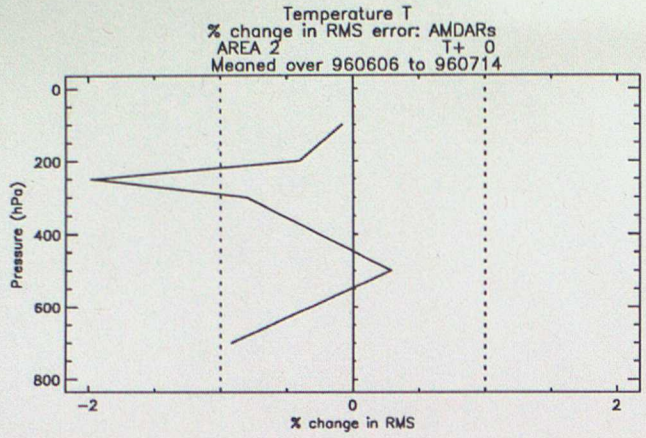
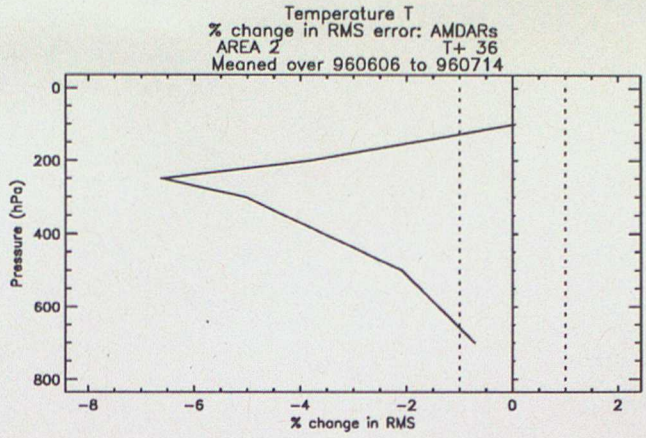
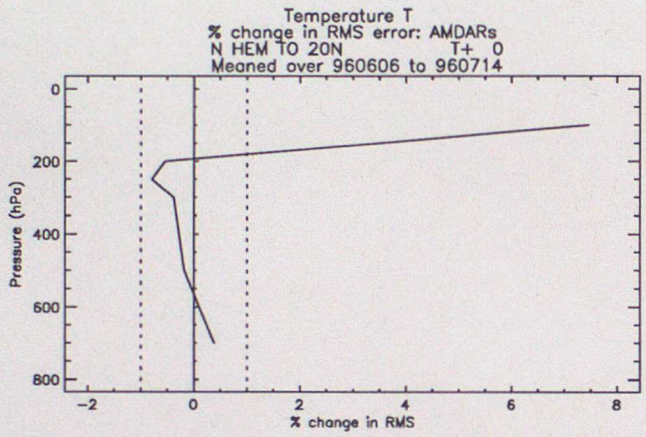
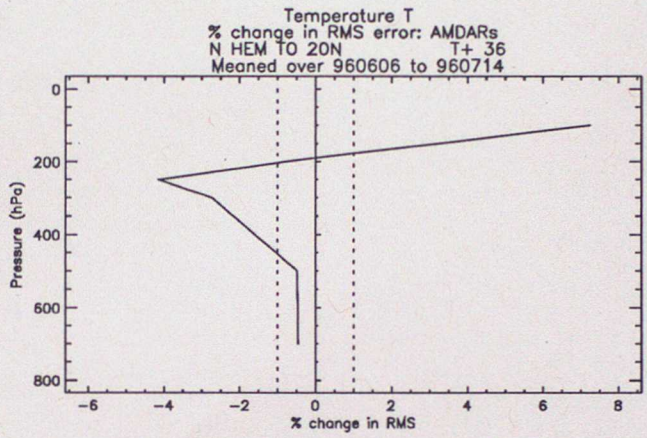

Temperature T
% change in RMS error: Air reps
S HEM FROM 20S T+ 36
Meaned over 960606 to 960714
Pressure (hPa)
% change in RMS

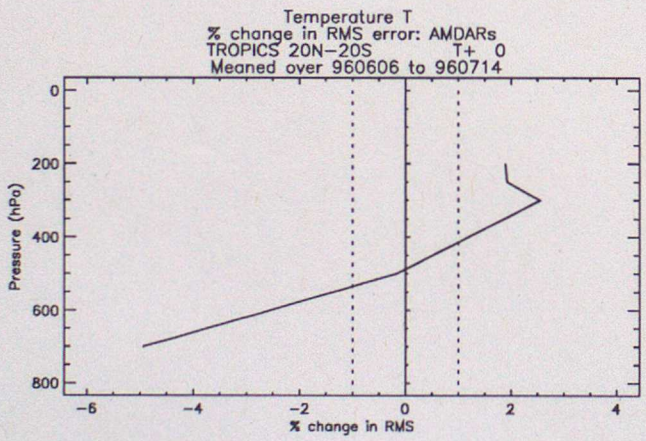
FIGURE 4. 12

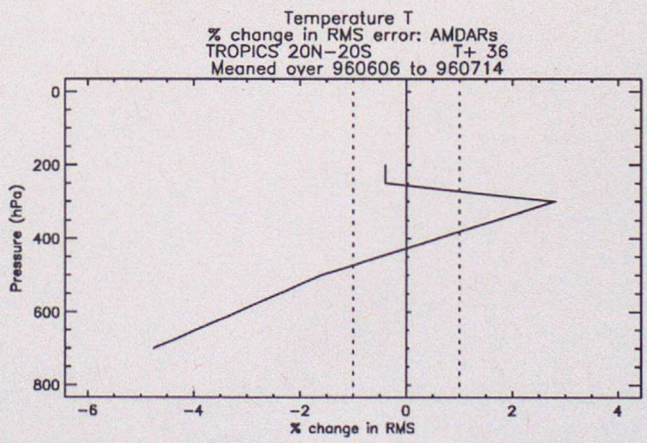

Temperature T
% change in RMS error: AMDARs
AREA 2 T+ 0
Meaned over 960606 to 960714
Pressure (hPa)
% change in RMS

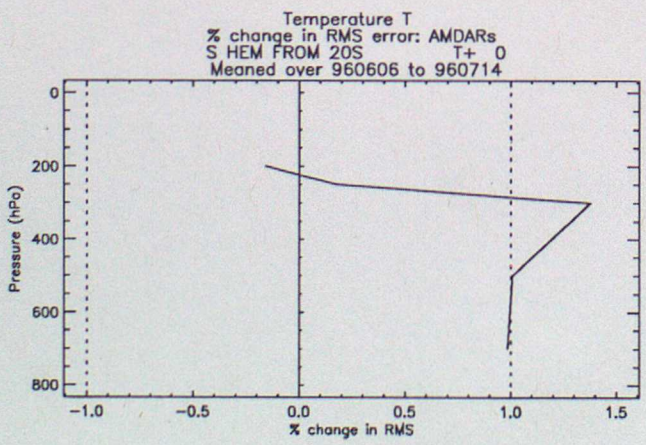

Temperature T
% change in RMS error: AMDARs
AREA 2 T+ 36
Meaned over 960606 to 960714
Pressure (hPa)
% change in RMS


Temperature T
% change in RMS error: AMDARs
N HEM TO 20N T+ 0
Meaned over 960606 to 960714
Pressure (hPa)
% change in RMS


Temperature T
% change in RMS error: AMDARs
N HEM TO 20N T+ 36
Meaned over 960606 to 960714
Pressure (hPa)
% change in RMS


Temperature T
% change in RMS error: AMDARs
TROPICS 20N-20S T+ 0
Meaned over 960606 to 960714
Pressure (hPa)
% change in RMS


Temperature T
% change in RMS error: AMDARs
TROPICS 20N-20S T+ 36
Meaned over 960606 to 960714
Pressure (hPa)
% change in RMS


Temperature T
% change in RMS error: AMDARs
S HEM FROM 20S T+ 0
Meaned over 960606 to 960714
Pressure (hPa)
% change in RMS

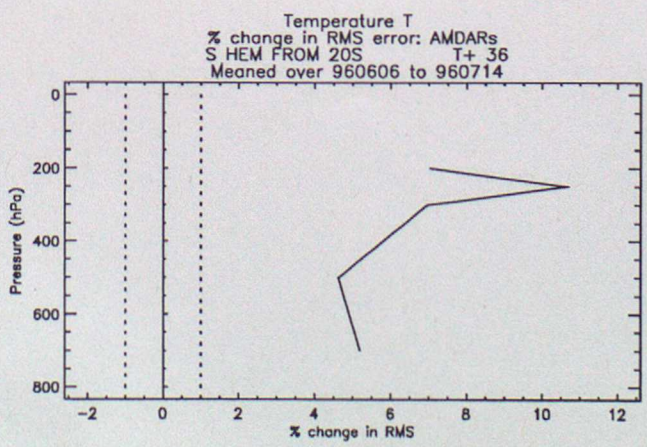
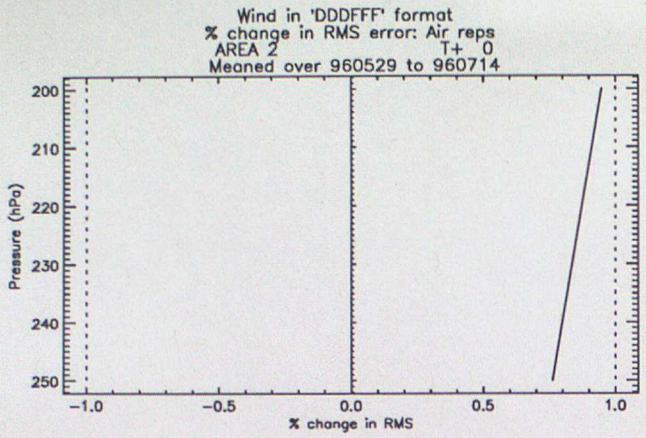
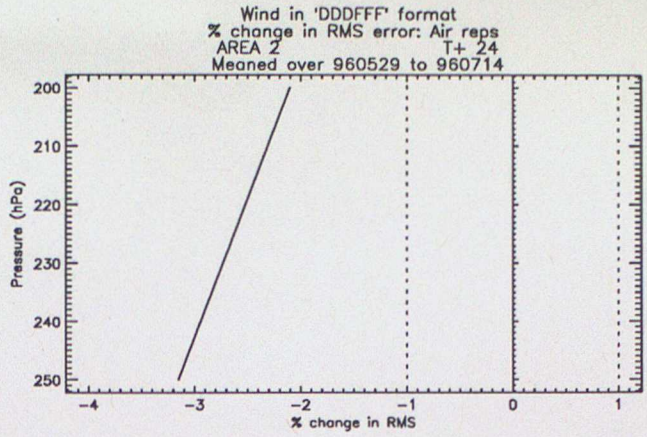
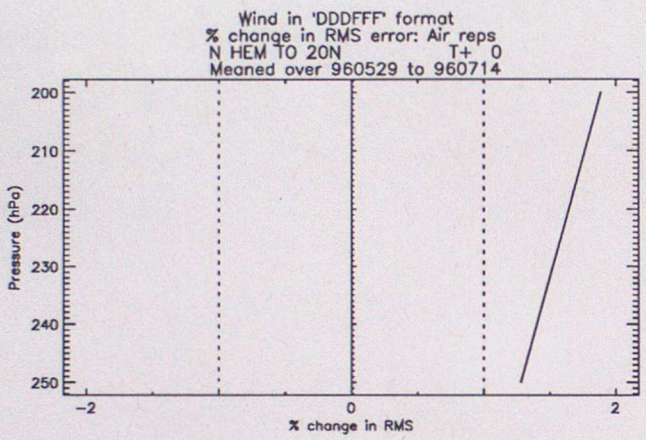
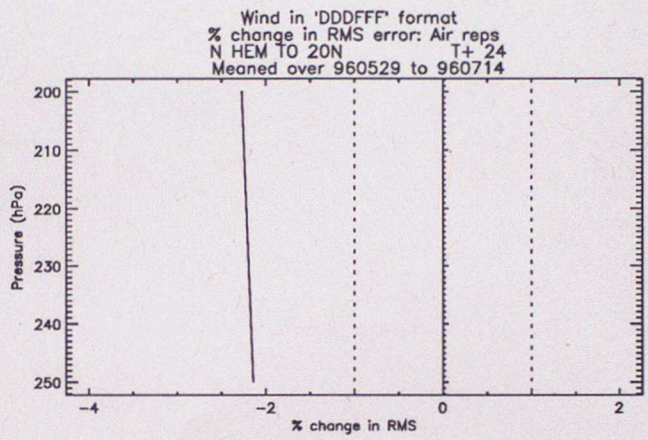

Temperature T
% change in RMS error: AMDARs
S HEM FROM 20S T+ 36
Meaned over 960606 to 960714
Pressure (hPa)
% change in RMS

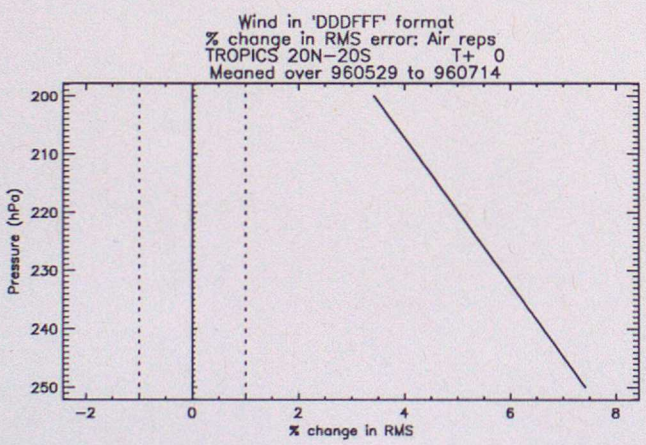
FIGURE 4. 13

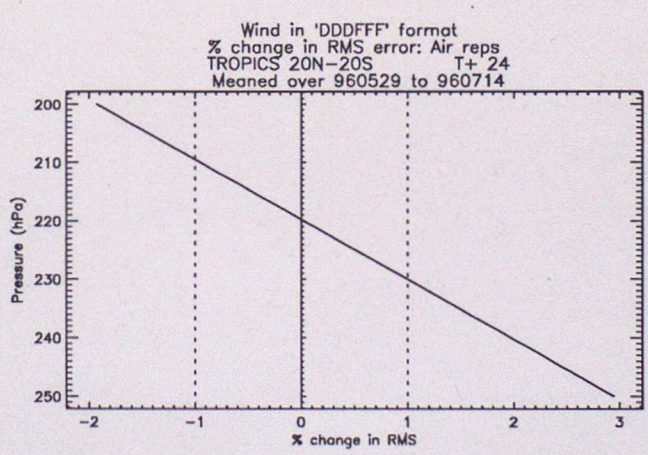

Wind in 'DDDFFF' format
% change in RMS error: Air reps
AREA 2 T+ 0
Meaned over 960529 to 960714
Pressure (hPa)
200
210
220
230
240
250
−1.0
−0.5
0.0
0.5
1.0
% change in RMS

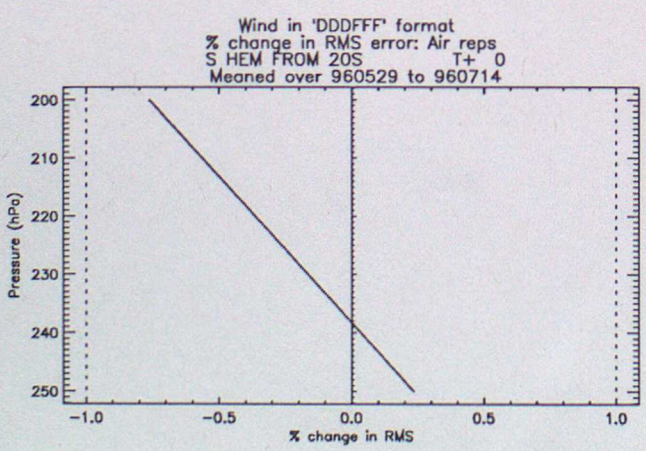

Wind in 'DDDFFF' format
% change in RMS error: Air reps
AREA 2 T+ 24
Meaned over 960529 to 960714
Pressure (hPa)
200
210
220
230
240
250
−4
−3
−2
−1
0
1
% change in RMS


Wind in 'DDDFFF' format
% change in RMS error: Air reps
N HEM TO 20N T+ 0
Meaned over 960529 to 960714
Pressure (hPa)
200
210
220
230
240
250
−2
0
2
% change in RMS


Wind in 'DDDFFF' format
% change in RMS error: Air reps
N HEM TO 20N T+ 24
Meaned over 960529 to 960714
Pressure (hPa)
200
210
220
230
240
250
−4
−2
0
2
% change in RMS


Wind in 'DDDFFF' format
% change in RMS error: Air reps
TROPICS 20N−20S T+ 0
Meaned over 960529 to 960714
Pressure (hPa)
200
210
220
230
240
250
−2
0
2
4
6
8
% change in RMS


Wind in 'DDDFFF' format
% change in RMS error: Air reps
TROPICS 20N−20S T+ 24
Meaned over 960529 to 960714
Pressure (hPa)
200
210
220
230
240
250
−2
−1
0
1
2
3
% change in RMS


Wind in 'DDDFFF' format
% change in RMS error: Air reps
S HEM FROM 20S T+ 0
Meaned over 960529 to 960714
Pressure (hPa)
200
210
220
230
240
250
−1.0
−0.5
0.0
0.5
1.0
% change in RMS

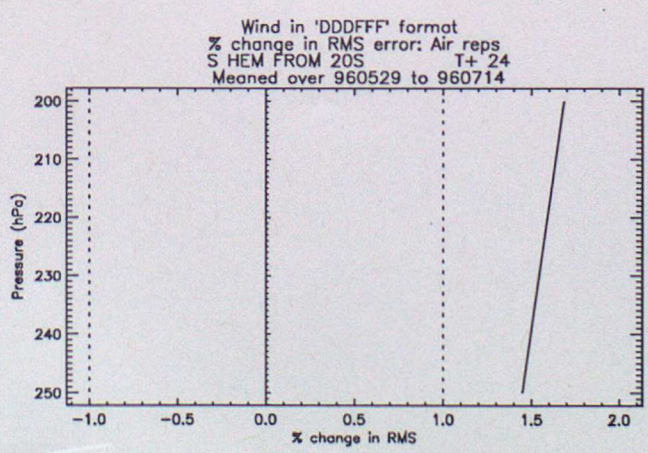
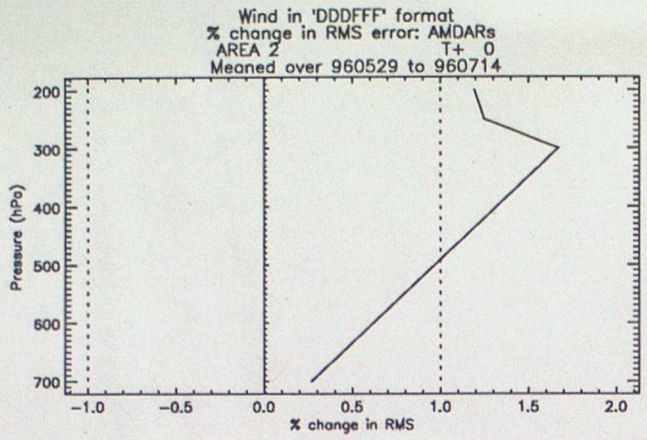
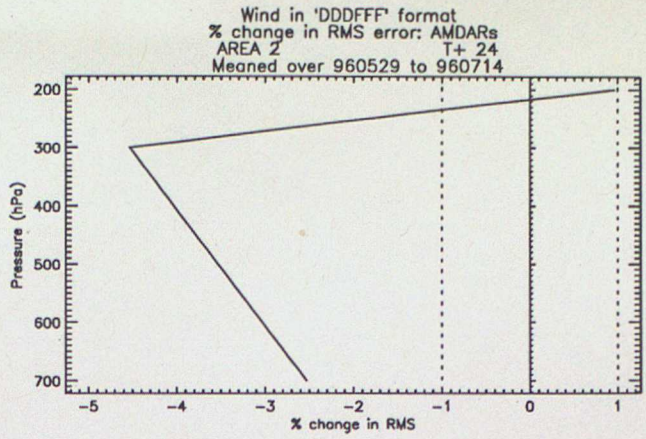
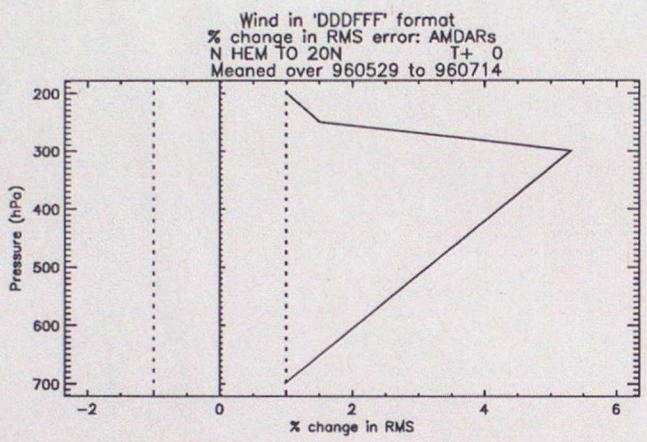
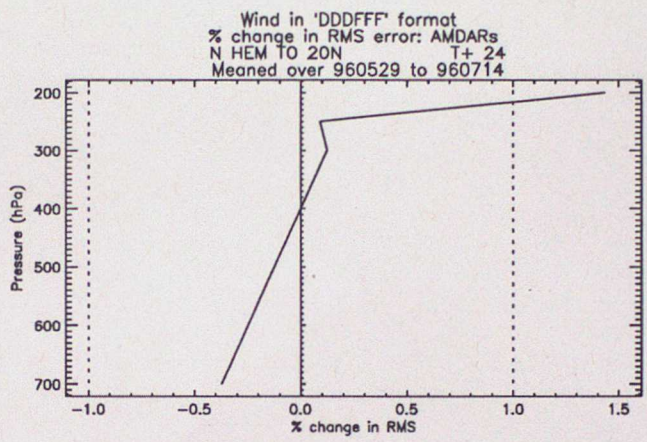

Wind in 'DDDFFF' format
% change in RMS error: Air reps
S HEM FROM 20S T+ 24
Meaned over 960529 to 960714
Pressure (hPa)
200
210
220
230
240
250
−1.0
−0.5
0.0
0.5
1.0
1.5
2.0
% change in RMS

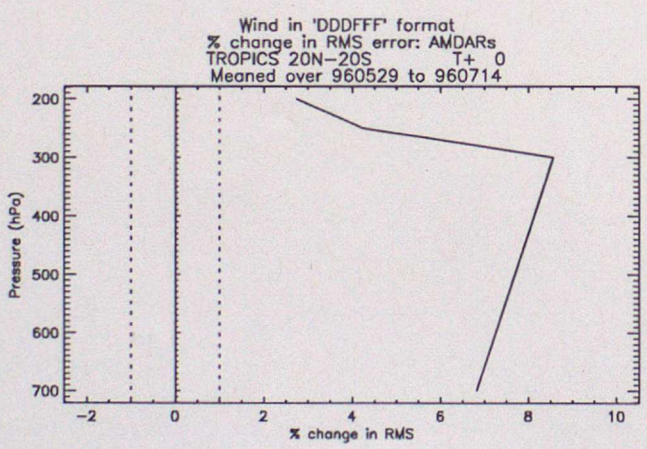
FIGURE 4. 14

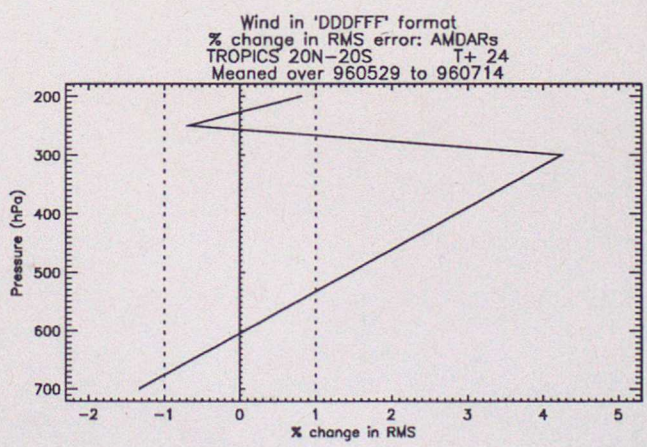

Wind in 'DDDFFF' format
% change in RMS error: AMDARs
AREA 2 T+ 0
Meaned over 960529 to 960714
Pressure (hPa)
% change in RMS

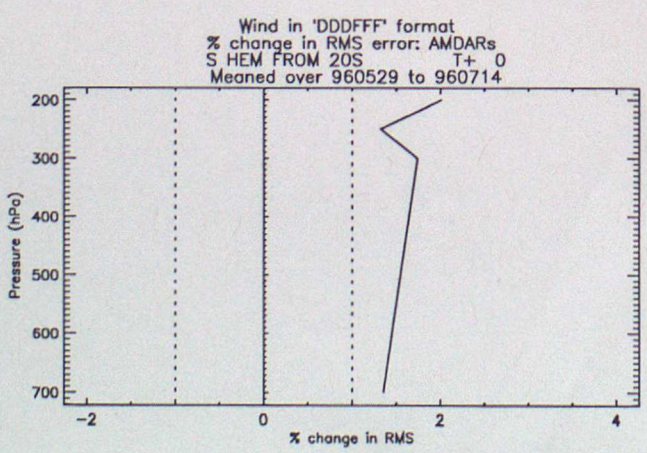

Wind in 'DDDFFF' format
% change in RMS error: AMDARs
AREA 2 T+ 24
Meaned over 960529 to 960714
Pressure (hPa)
% change in RMS


Wind in 'DDDFFF' format
% change in RMS error: AMDARs
N HEM TO 20N T+ 0
Meaned over 960529 to 960714
Pressure (hPa)
% change in RMS


Wind in 'DDDFFF' format
% change in RMS error: AMDARs
N HEM TO 20N T+ 24
Meaned over 960529 to 960714
Pressure (hPa)
% change in RMS


Wind in 'DDDFFF' format
% change in RMS error: AMDARs
TROPICS 20N-20S T+ 0
Meaned over 960529 to 960714
Pressure (hPa)
% change in RMS


Wind in 'DDDFFF' format
% change in RMS error: AMDARs
TROPICS 20N-20S T+ 24
Meaned over 960529 to 960714
Pressure (hPa)
% change in RMS


Wind in 'DDDFFF' format
% change in RMS error: AMDARs
S HEM FROM 20S T+ 0
Meaned over 960529 to 960714
Pressure (hPa)
% change in RMS

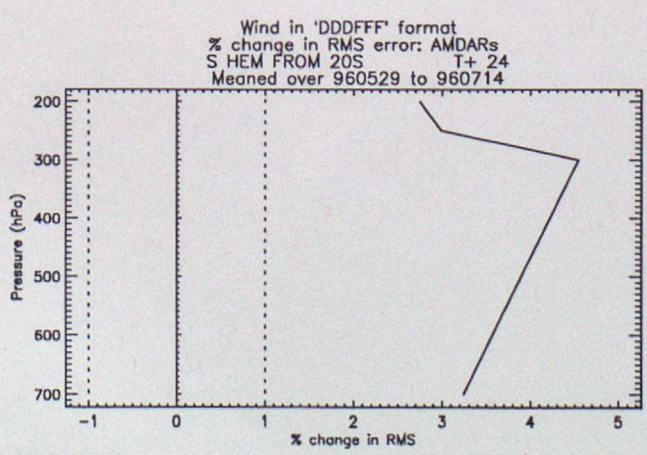
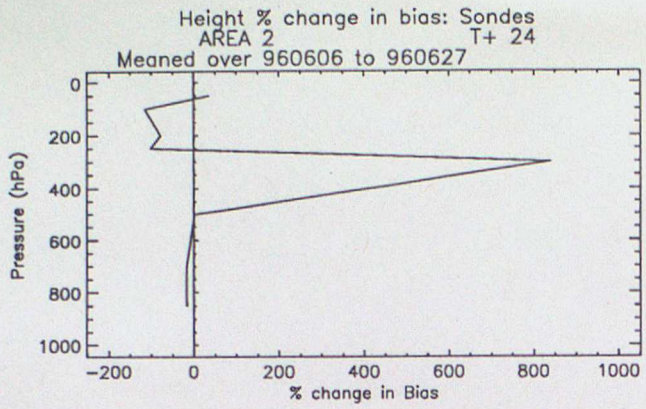
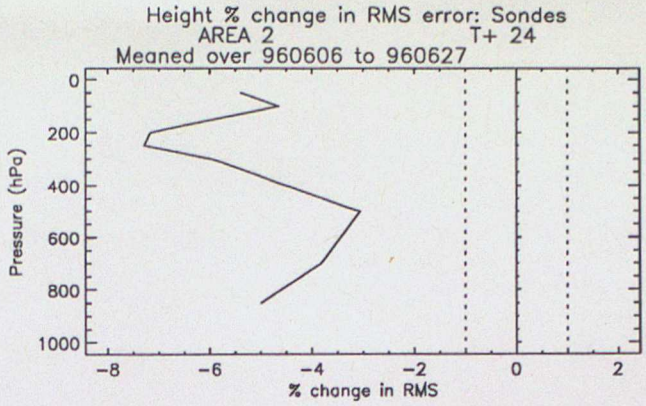
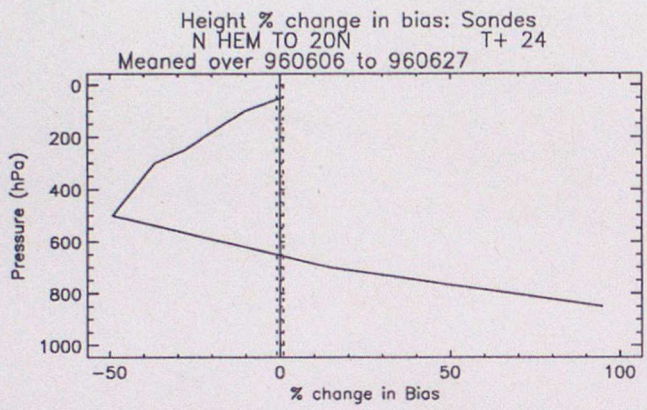
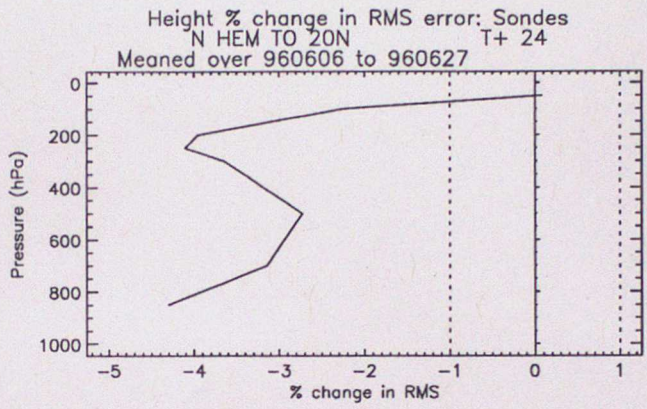

Wind in 'DDDFFF' format
% change in RMS error: AMDARs
S HEM FROM 20S T+ 24
Meaned over 960529 to 960714
Pressure (hPa)
% change in RMS

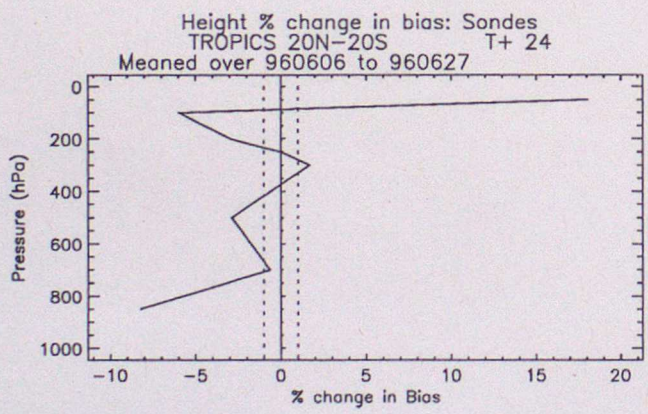
FIGURE 4. 15

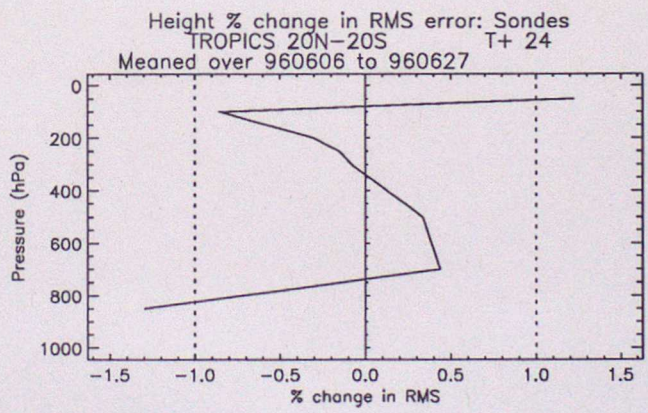

Height % change in bias: Sondes
AREA 2 T+ 24
Meaned over 960606 to 960627
Pressure (hPa)
0
200
400
600
800
1000
−200
0
200
400
600
800
1000
% change in Bias

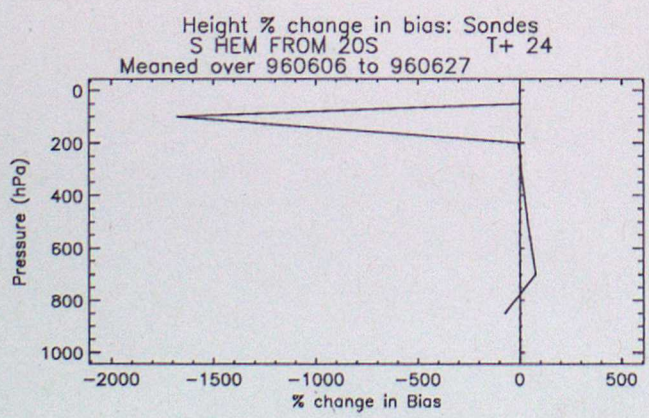

Height % change in RMS error: Sondes
AREA 2 T+ 24
Meaned over 960606 to 960627
Pressure (hPa)
0
200
400
600
800
1000
−8
−6
−4
−2
0
2
% change in RMS


Height % change in bias: Sondes
N HEM TO 20N T+ 24
Meaned over 960606 to 960627
Pressure (hPa)
0
200
400
600
800
1000
−50
0
50
100
% change in Bias


Height % change in RMS error: Sondes
N HEM TO 20N T+ 24
Meaned over 960606 to 960627
Pressure (hPa)
0
200
400
600
800
1000
−5
−4
−3
−2
−1
0
1
% change in RMS


Height % change in bias: Sondes
TROPICS 20N−20S T+ 24
Meaned over 960606 to 960627
Pressure (hPa)
0
200
400
600
800
1000
−10
−5
0
5
10
15
20
% change in Bias


Height % change in RMS error: Sondes
TROPICS 20N−20S T+ 24
Meaned over 960606 to 960627
Pressure (hPa)
0
200
400
600
800
1000
−1.5
−1.0
−0.5
0.0
0.5
1.0
1.5
% change in RMS


Height % change in bias: Sondes
S HEM FROM 20S T+ 24
Meaned over 960606 to 960627
Pressure (hPa)
0
200
400
600
800
1000
−2000
−1500
−1000
−500
0
500
% change in Bias

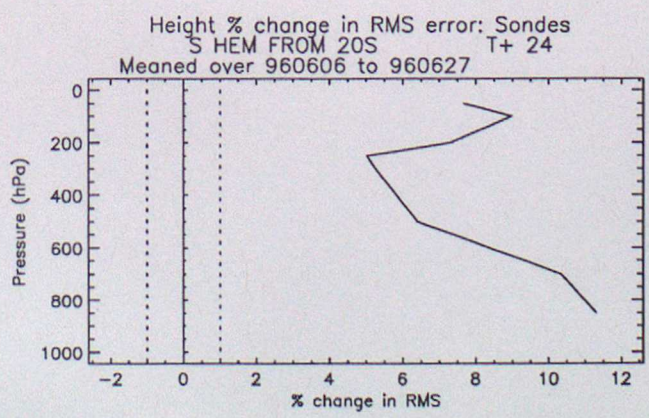
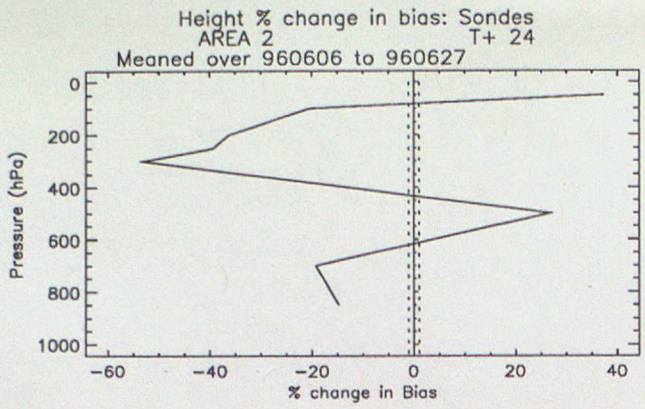
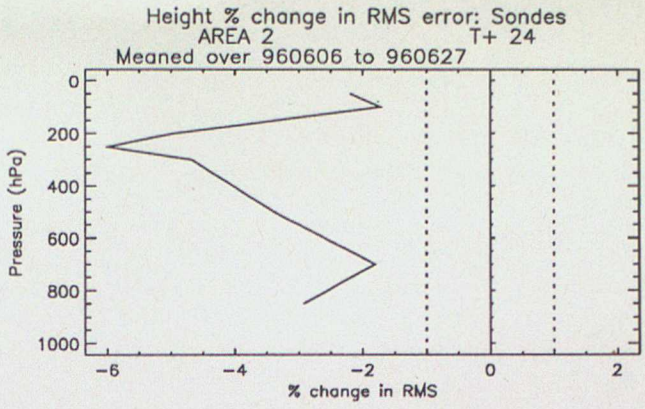
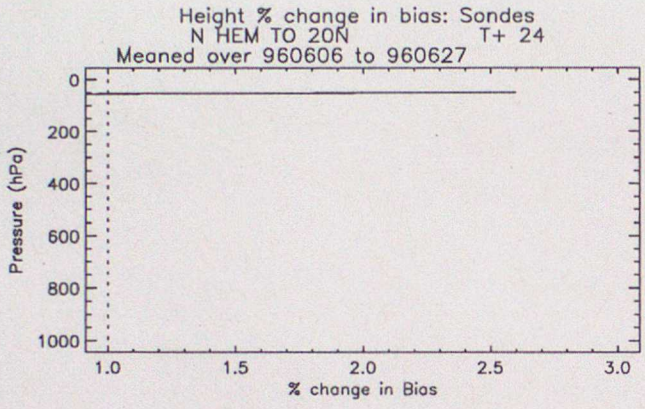
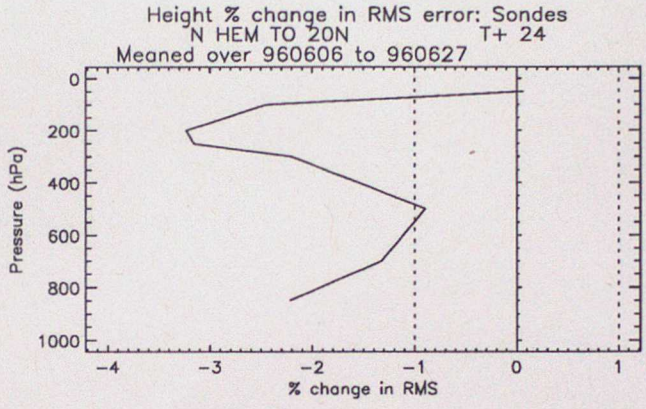

Height % change in RMS error: Sondes
S HEM FROM 20S T+ 24
Meaned over 960606 to 960627
Pressure (hPa)
0
200
400
600
800
1000
−2
0
2
4
6
8
10
12
% change in RMS

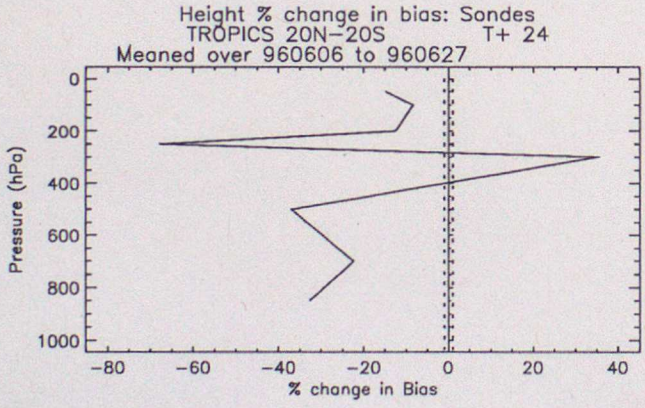
FIGURE 4. 16

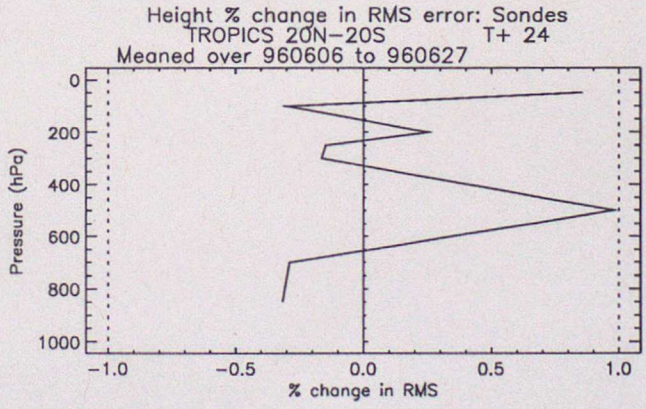

Height % change in bias: Sondes
AREA 2 T+ 24
Meaned over 960606 to 960627
Pressure (hPa)
% change in Bias

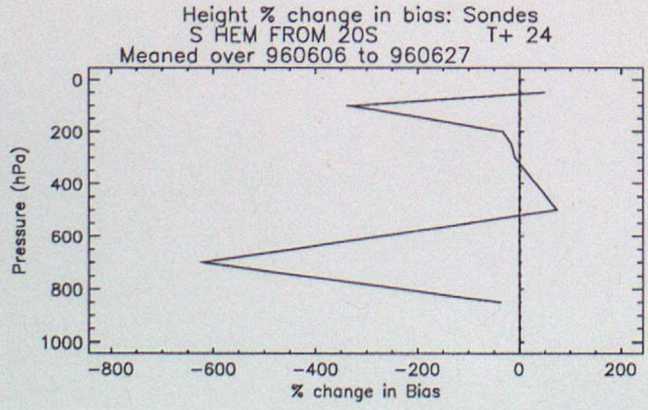

Height % change in RMS error: Sondes
AREA 2 T+ 24
Meaned over 960606 to 960627
Pressure (hPa)
% change in RMS


Height % change in bias: Sondes
N HEM TO 20N T+ 24
Meaned over 960606 to 960627
Pressure (hPa)
% change in Bias


Height % change in RMS error: Sondes
N HEM TO 20N T+ 24
Meaned over 960606 to 960627
Pressure (hPa)
% change in RMS


Height % change in bias: Sondes
TROPICS 20N-20S T+ 24
Meaned over 960606 to 960627
Pressure (hPa)
% change in Bias


Height % change in RMS error: Sondes
TROPICS 20N-20S T+ 24
Meaned over 960606 to 960627
Pressure (hPa)
% change in RMS


Height % change in bias: Sondes
S HEM FROM 20S T+ 24
Meaned over 960606 to 960627
Pressure (hPa)
% change in Bias

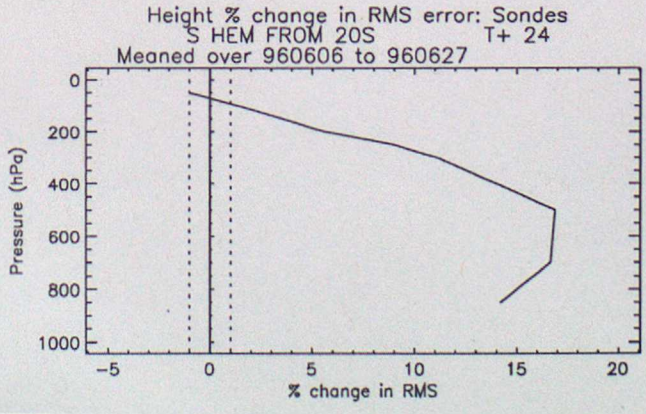
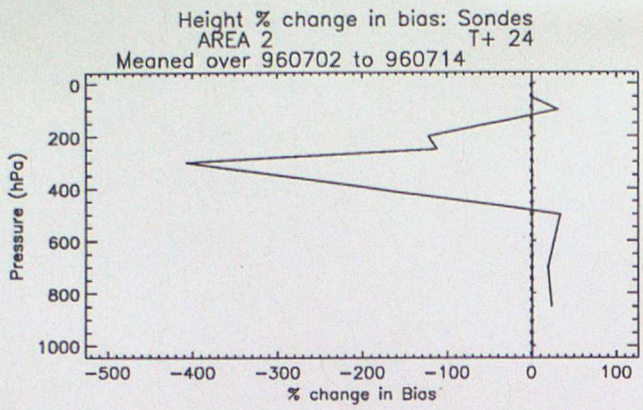
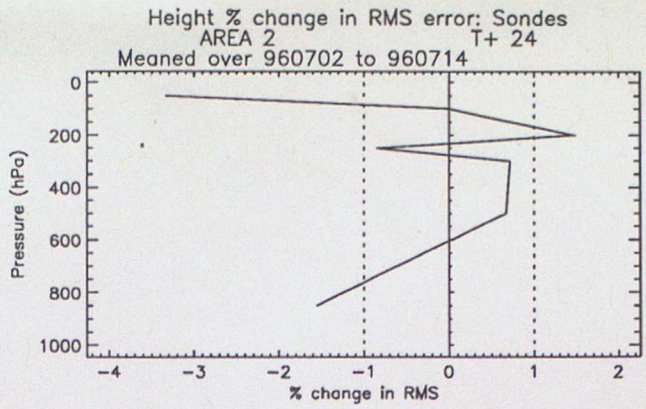
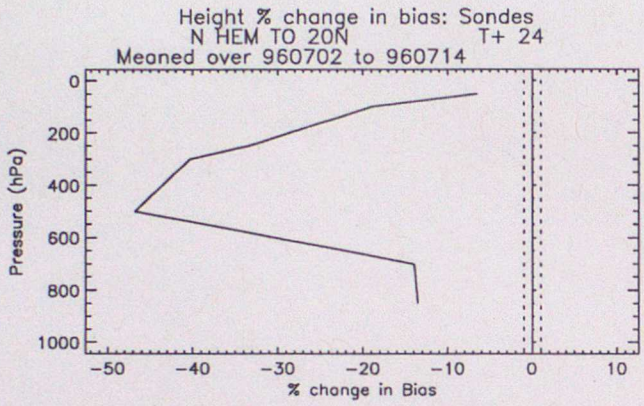
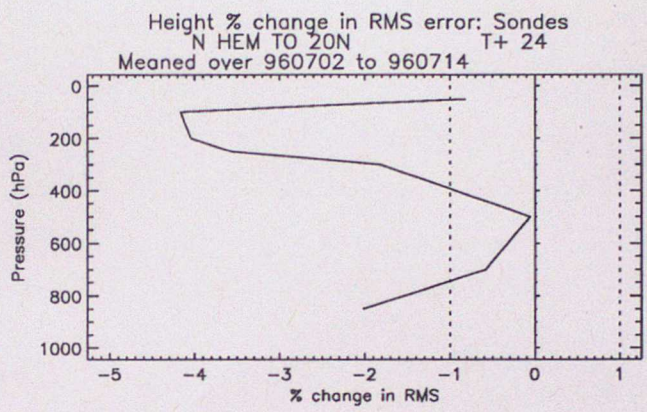

Height % change in RMS error: Sondes
S HEM FROM 20S T+ 24
Meaned over 960606 to 960627
Pressure (hPa)
% change in RMS

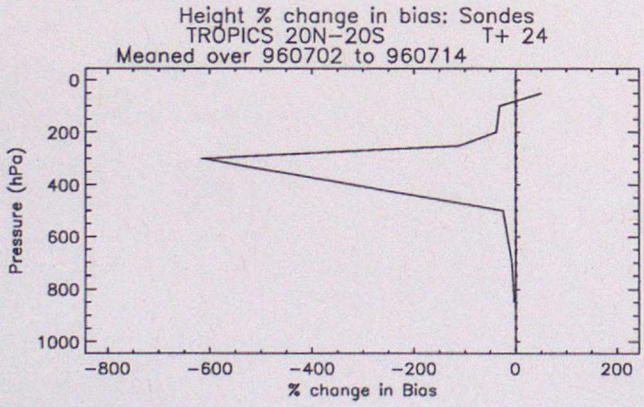
FIGURE 4. 17

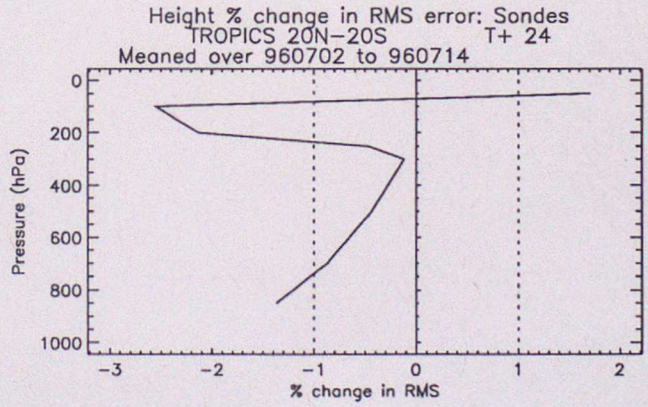

Height % change in bias: Sondes
AREA 2 T+ 24
Meaned over 960702 to 960714
Pressure (hPa)
% change in Bias

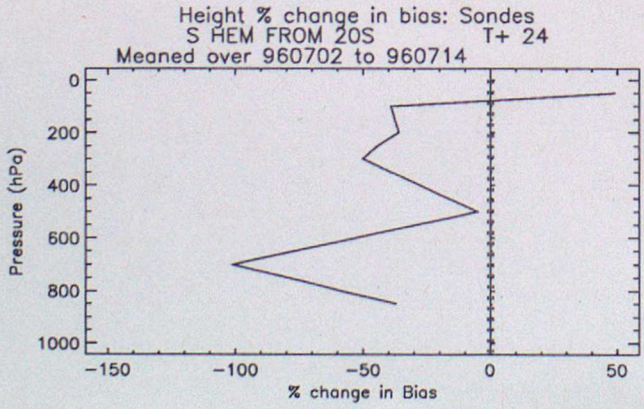

Height % change in RMS error: Sondes
AREA 2 T+ 24
Meaned over 960702 to 960714
Pressure (hPa)
% change in RMS


Height % change in bias: Sondes
N HEM TO 20N T+ 24
Meaned over 960702 to 960714
Pressure (hPa)
% change in Bias


Height % change in RMS error: Sondes
N HEM TO 20N T+ 24
Meaned over 960702 to 960714
Pressure (hPa)
% change in RMS


Height % change in bias: Sondes
TROPICS 20N-20S T+ 24
Meaned over 960702 to 960714
Pressure (hPa)
% change in Bias


Height % change in RMS error: Sondes
TROPICS 20N-20S T+ 24
Meaned over 960702 to 960714
Pressure (hPa)
% change in RMS


Height % change in bias: Sondes
S HEM FROM 20S T+ 24
Meaned over 960702 to 960714
Pressure (hPa)
% change in Bias

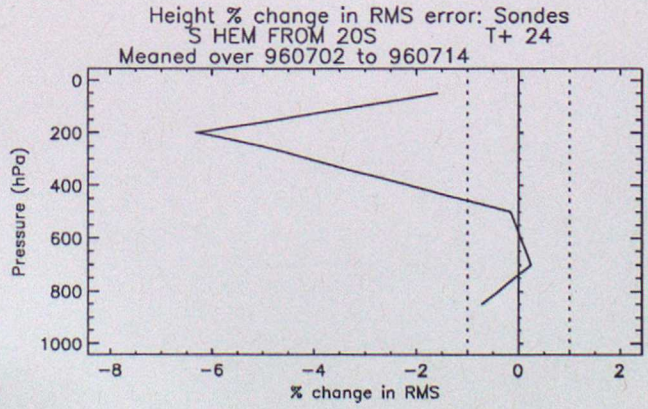

Height % change in RMS error: Sondes
S HEM FROM 20S T+ 24
Meaned over 960702 to 960714
Pressure (hPa)
% change in RMS

FIGURE 4. 18

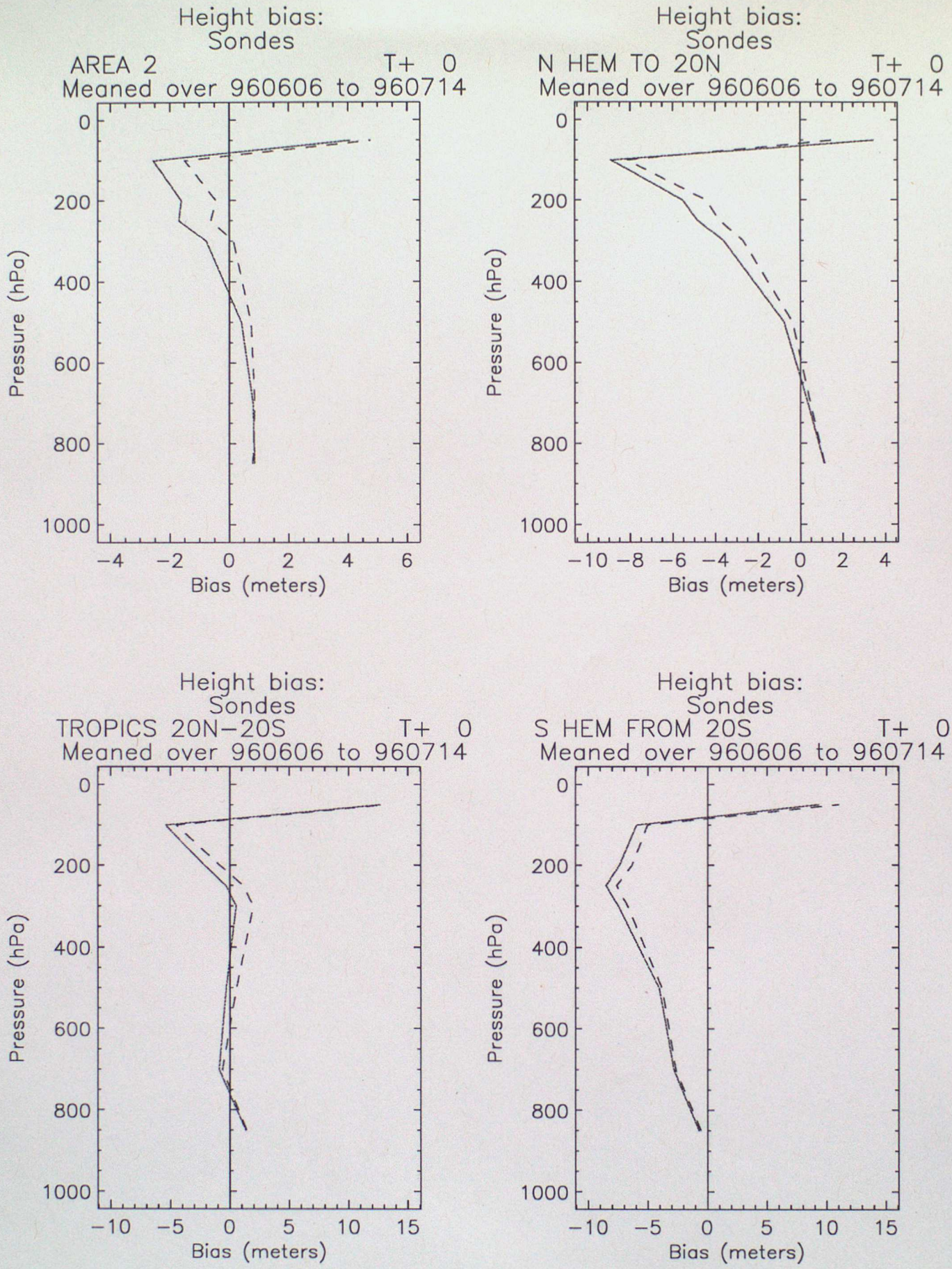

Height bias:
Sondes
AREA 2 T+ 0
Meaned over 960606 to 960714
Pressure (hPa)
0
200
400
600
800
1000
−4 −2 0 2 4 6
Bias (meters)
Height bias:
Sondes
N HEM TO 20N T+ 0
Meaned over 960606 to 960714
Pressure (hPa)
0
200
400
600
800
1000
−10 −8 −6 −4 −2 0 2 4
Bias (meters)
Height bias:
Sondes
TROPICS 20N−20S T+ 0
Meaned over 960606 to 960714
Pressure (hPa)
0
200
400
600
800
1000
−10 −5 0 5 10 15
Bias (meters)
Height bias:
Sondes
S HEM FROM 20S T+ 0
Meaned over 960606 to 960714
Pressure (hPa)
0
200
400
600
800
1000
−10 −5 0 5 10 15
Bias (meters)

FIGURE 4. 19

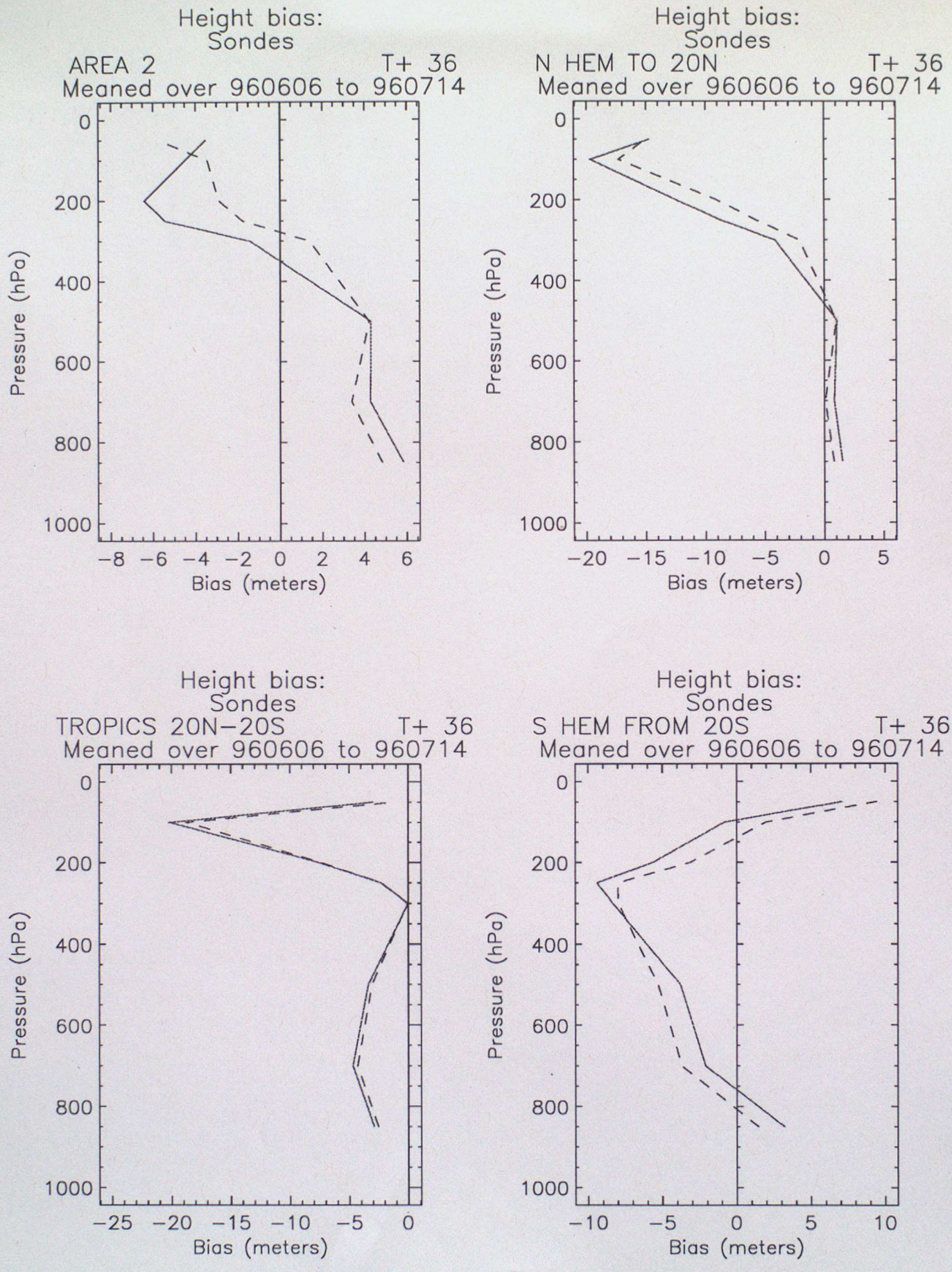

Height bias:
Sondes
AREA 2
T+ 36
Meaned over 960606 to 960714
Pressure (hPa)
0
200
400
600
800
1000
−8 −6 −4 −2 0 2 4 6
Bias (meters)
Height bias:
Sondes
N HEM TO 20N
T+ 36
Meaned over 960606 to 960714
Pressure (hPa)
0
200
400
600
800
1000
−20 −15 −10 −5 0 5
Bias (meters)
Height bias:
Sondes
TROPICS 20N−20S
T+ 36
Meaned over 960606 to 960714
Pressure (hPa)
0
200
400
600
800
1000
−25 −20 −15 −10 −5 0
Bias (meters)
Height bias:
Sondes
S HEM FROM 20S
T+ 36
Meaned over 960606 to 960714
Pressure (hPa)
0
200
400
600
800
1000
−10 −5 0 5 10
Bias (meters)

FIGURE 4. 20

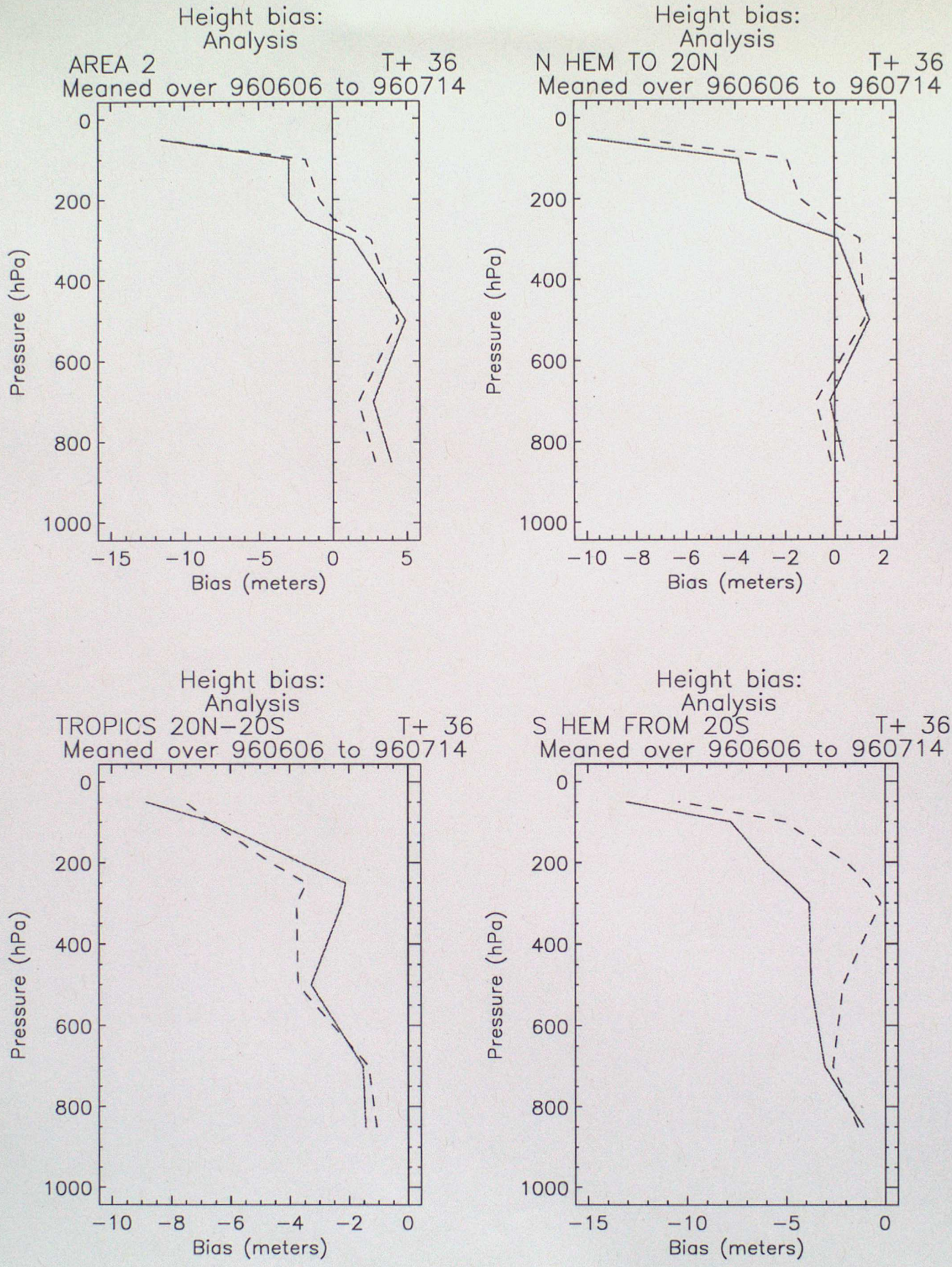
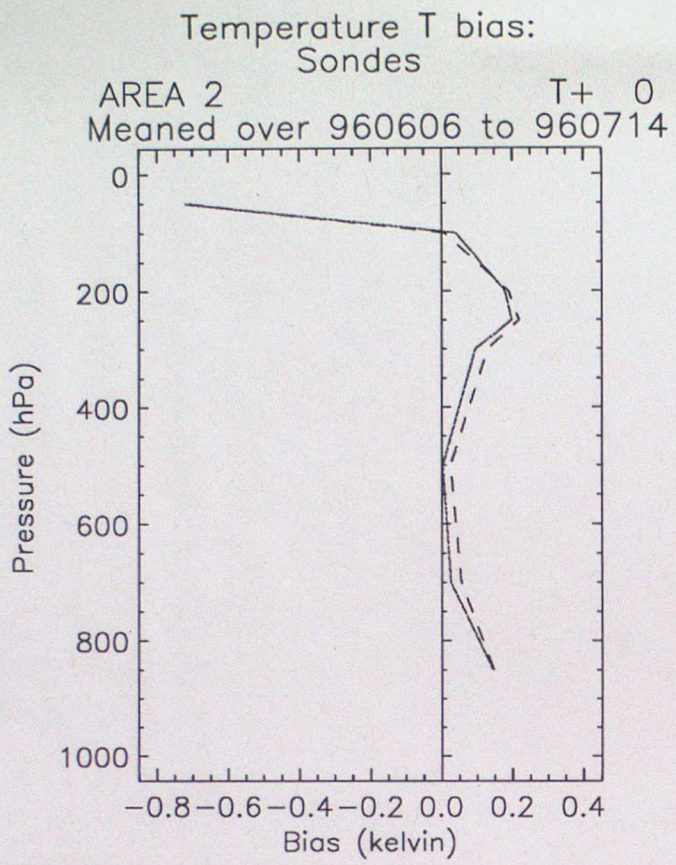
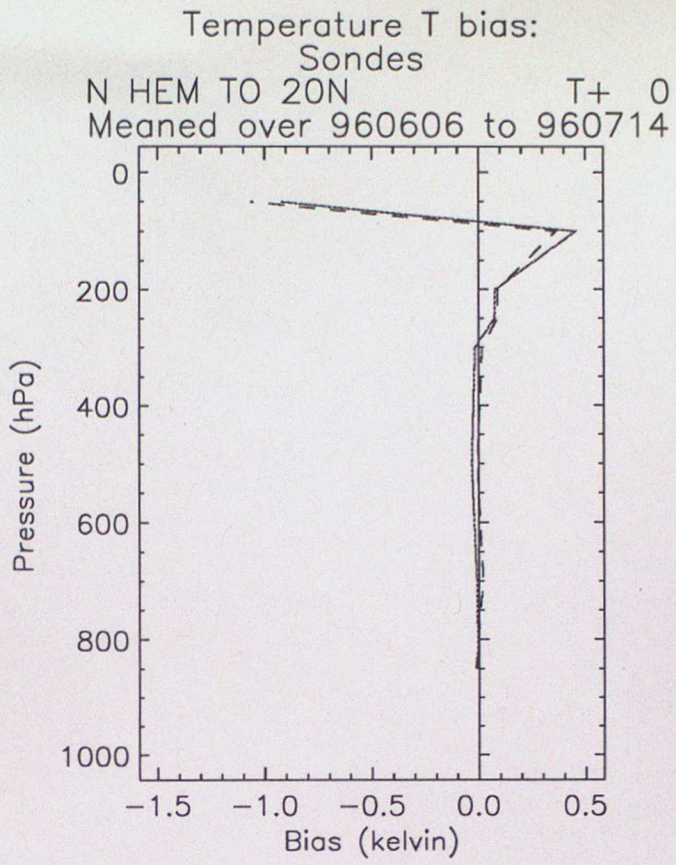
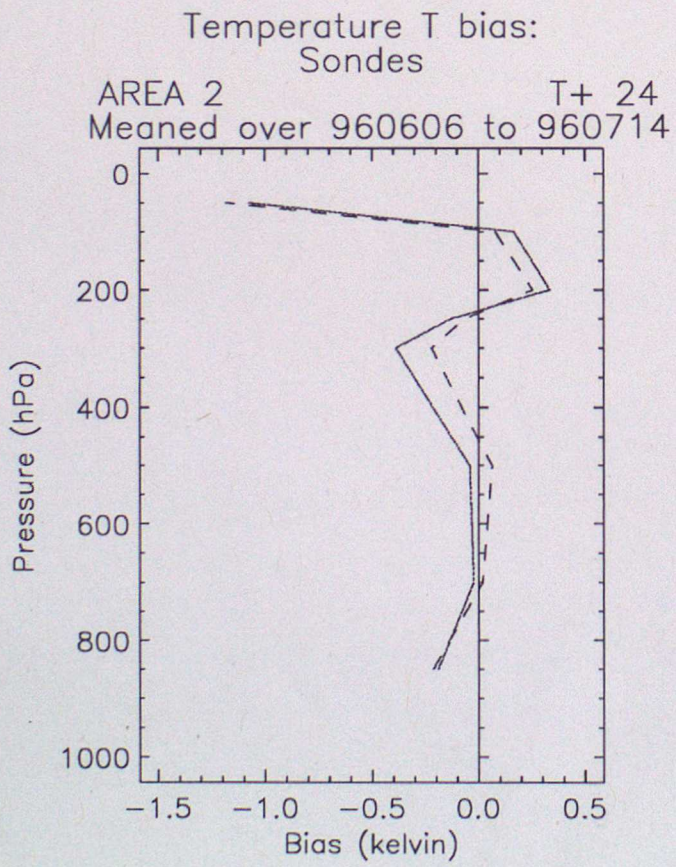

Height bias:
Analysis
AREA 2
T+ 36
Meaned over 960606 to 960714
Pressure (hPa)
0
200
400
600
800
1000
−15
−10
−5
0
5
Bias (meters)
Height bias:
Analysis
N HEM TO 20N
T+ 36
Meaned over 960606 to 960714
Pressure (hPa)
0
200
400
600
800
1000
−10
−8
−6
−4
−2
0
2
Bias (meters)
Height bias:
Analysis
TROPICS 20N−20S
T+ 36
Meaned over 960606 to 960714
Pressure (hPa)
0
200
400
600
800
1000
−10
−8
−6
−4
−2
0
Bias (meters)
Height bias:
Analysis
S HEM FROM 20S
T+ 36
Meaned over 960606 to 960714
Pressure (hPa)
0
200
400
600
800
1000
−15
−10
−5
0
Bias (meters)

FIGURE 4. 21


Temperature T bias:
Sondes
AREA 2
T+ 0
Meaned over 960606 to 960714
Pressure (hPa)
0
200
400
600
800
1000
−0.8 −0.6 −0.4 −0.2 0.0 0.2 0.4
Bias (kelvin)


Temperature T bias:
Sondes
N HEM TO 20N
T+ 0
Meaned over 960606 to 960714
Pressure (hPa)
0
200
400
600
800
1000
−1.5 −1.0 −0.5 0.0 0.5
Bias (kelvin)


Temperature T bias:
Sondes
AREA 2
T+ 24
Meaned over 960606 to 960714
Pressure (hPa)
0
200
400
600
800
1000
−1.5 −1.0 −0.5 0.0 0.5
Bias (kelvin)

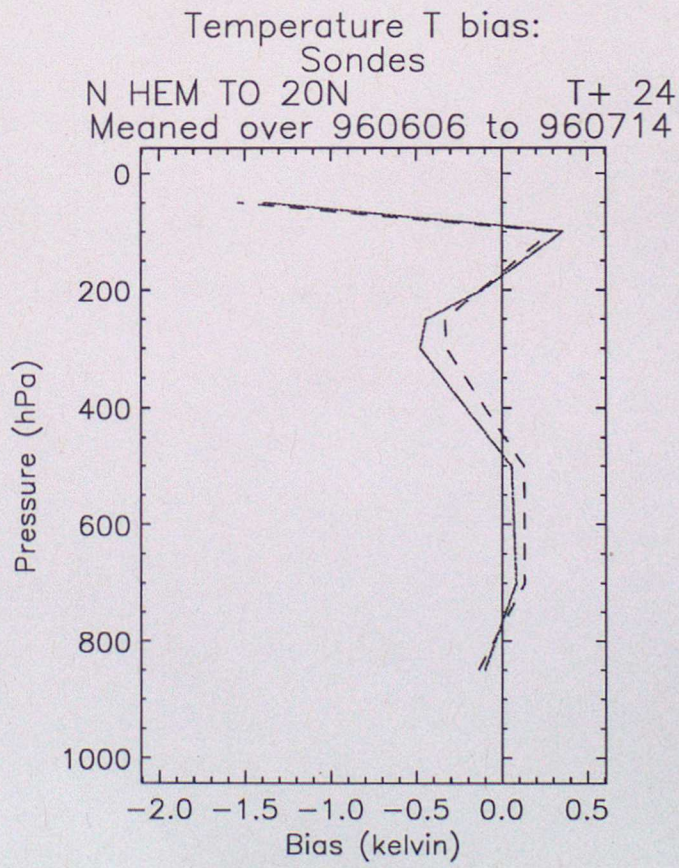

Temperature T bias:
Sondes
N HEM TO 20N
T+ 24
Meaned over 960606 to 960714
Pressure (hPa)
0
200
400
600
800
1000
−2.0 −1.5 −1.0 −0.5 0.0 0.5
Bias (kelvin)

FIGURE 4. 22

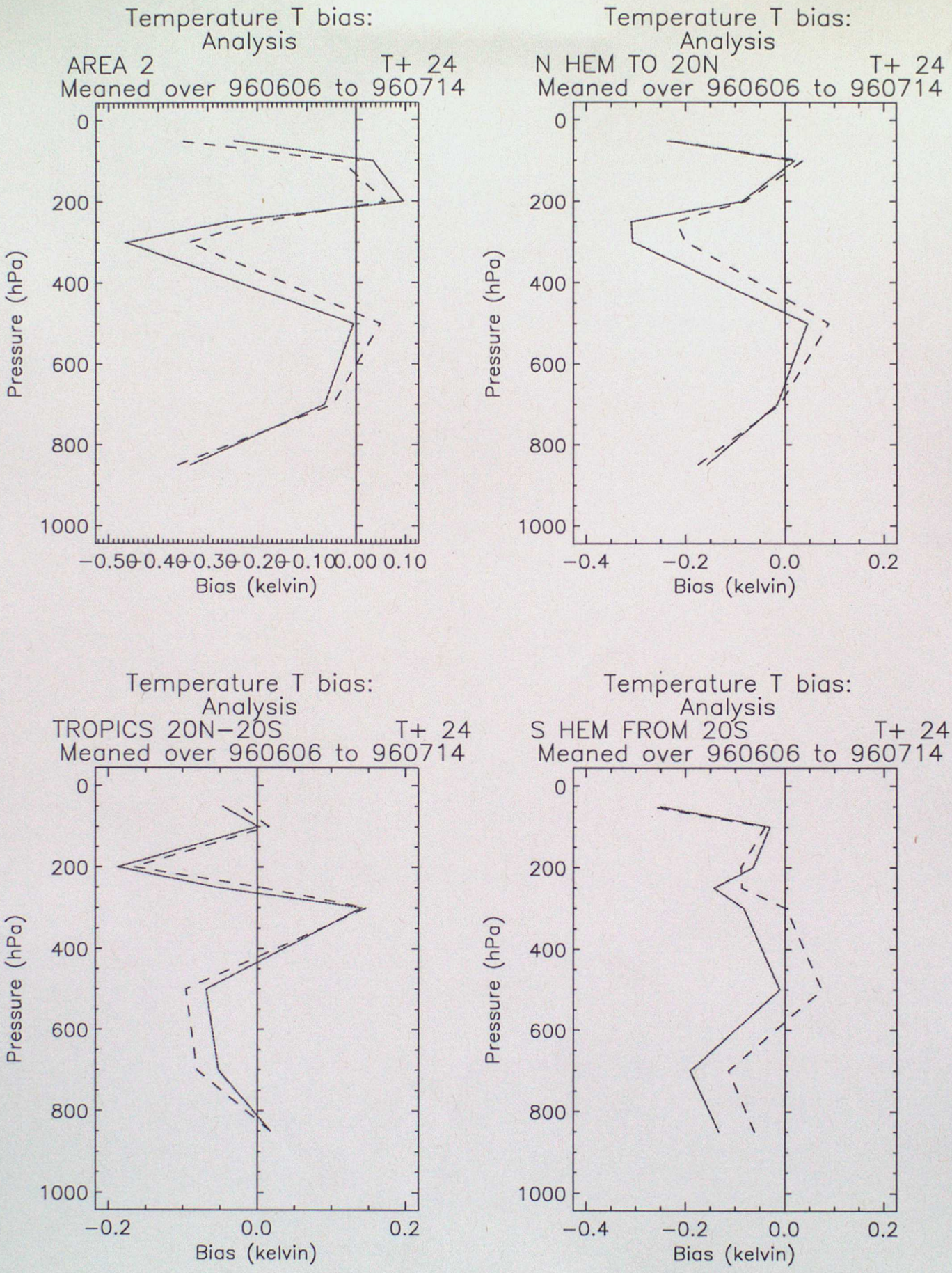
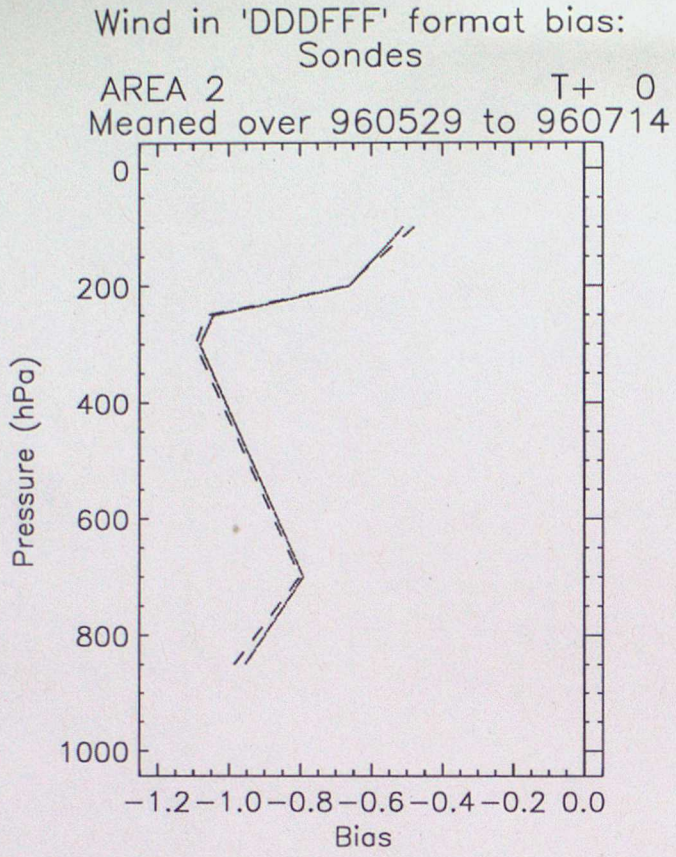
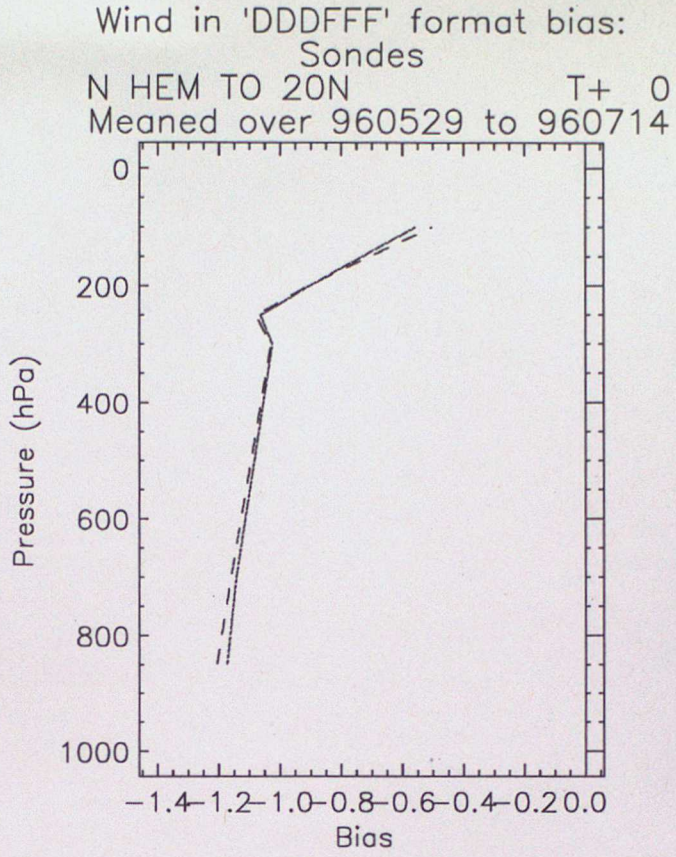
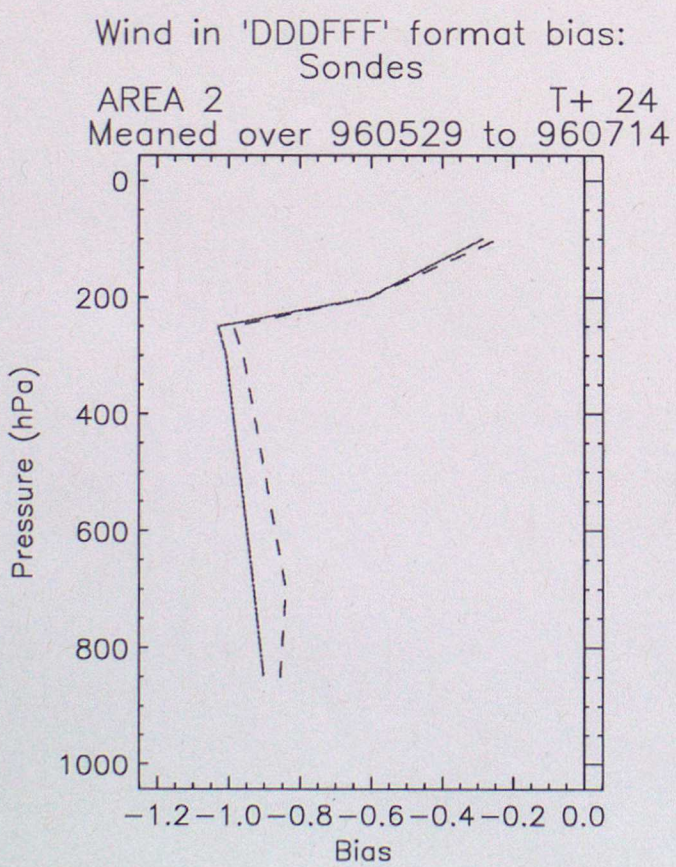

Temperature T bias:
Analysis
AREA 2
T+ 24
Meaned over 960606 to 960714
Pressure (hPa)
0
200
400
600
800
1000
−0.50 −0.40 −0.30 −0.20 −0.10 0.00 0.10
Bias (kelvin)
Temperature T bias:
Analysis
N HEM TO 20N
T+ 24
Meaned over 960606 to 960714
Pressure (hPa)
−0.4
−0.2
0.0
0.2
Bias (kelvin)
Temperature T bias:
Analysis
TROPICS 20N−20S
T+ 24
Meaned over 960606 to 960714
Pressure (hPa)
−0.2
0.0
0.2
Bias (kelvin)
Temperature T bias:
Analysis
S HEM FROM 20S
T+ 24
Meaned over 960606 to 960714
Pressure (hPa)
−0.4
−0.2
0.0
0.2
Bias (kelvin)

FIGURE 4. 23


Wind in 'DDDFFF' format bias:
Sondes
AREA 2
T+ 0
Meaned over 960529 to 960714
Pressure (hPa)
0
200
400
600
800
1000
−1.2 −1.0 −0.8 −0.6 −0.4 −0.2 0.0
Bias


Wind in 'DDDFFF' format bias:
Sondes
N HEM TO 20N
T+ 0
Meaned over 960529 to 960714
Pressure (hPa)
0
200
400
600
800
1000
−1.4 −1.2 −1.0 −0.8 −0.6 −0.4 −0.2 0.0
Bias


Wind in 'DDDFFF' format bias:
Sondes
AREA 2
T+ 24
Meaned over 960529 to 960714
Pressure (hPa)
0
200
400
600
800
1000
−1.2 −1.0 −0.8 −0.6 −0.4 −0.2 0.0
Bias

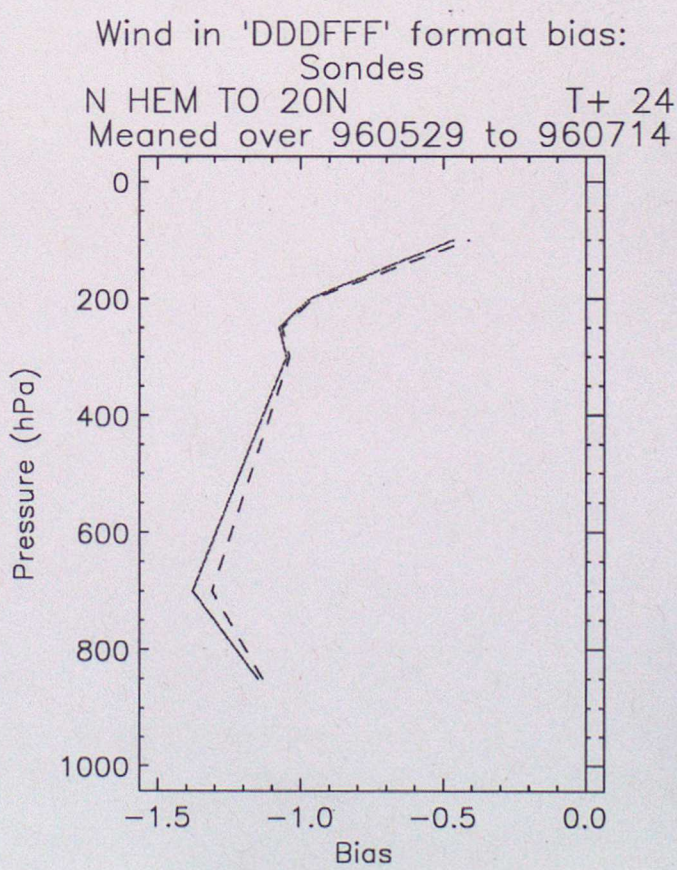
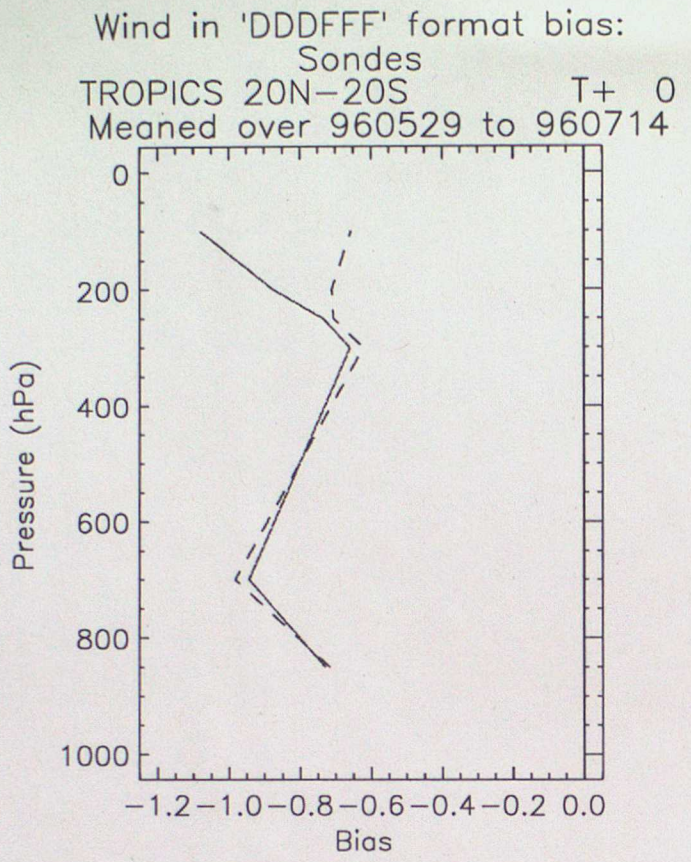
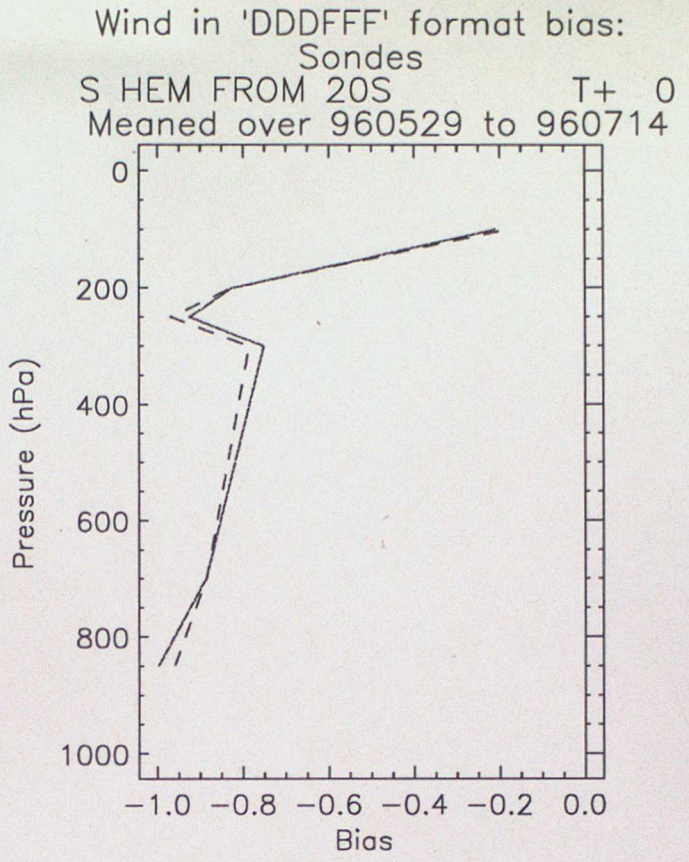
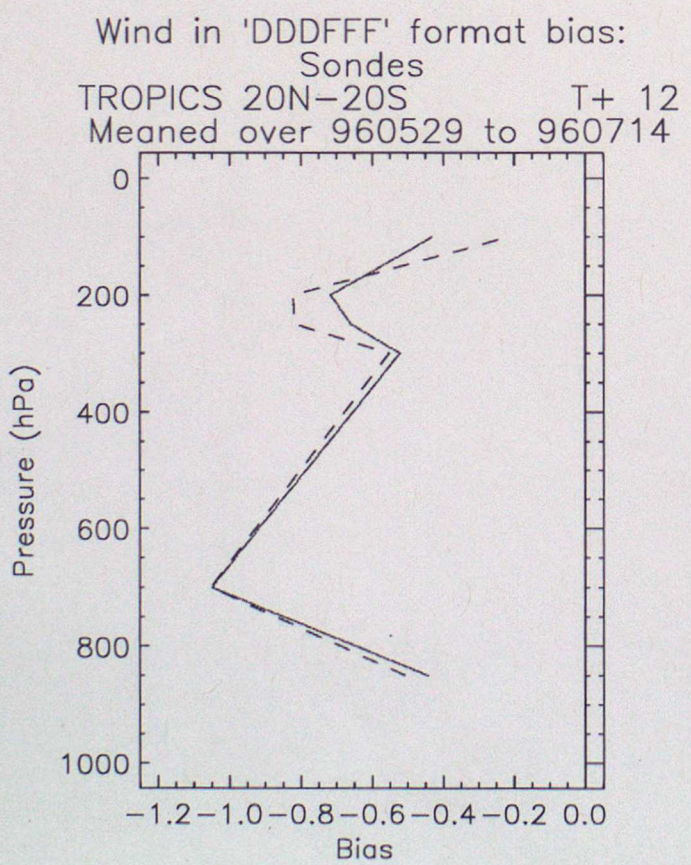

Wind in 'DDDFFF' format bias:
Sondes
N HEM TO 20N
T+ 24
Meaned over 960529 to 960714
Pressure (hPa)
0
200
400
600
800
1000
−1.5 −1.0 −0.5 0.0
Bias

FIGURE 4. 24


Wind in 'DDDFFF' format bias:
Sondes
TROPICS 20N-20S T+ 0
Meaned over 960529 to 960714
Pressure (hPa)
0
200
400
600
800
1000
-1.2 -1.0 -0.8 -0.6 -0.4 -0.2 0.0
Bias


Wind in 'DDDFFF' format bias:
Sondes
S HEM FROM 20S T+ 0
Meaned over 960529 to 960714
Pressure (hPa)
0
200
400
600
800
1000
-1.0 -0.8 -0.6 -0.4 -0.2 0.0
Bias


Wind in 'DDDFFF' format bias:
Sondes
TROPICS 20N-20S T+ 12
Meaned over 960529 to 960714
Pressure (hPa)
0
200
400
600
800
1000
-1.2 -1.0 -0.8 -0.6 -0.4 -0.2 0.0
Bias

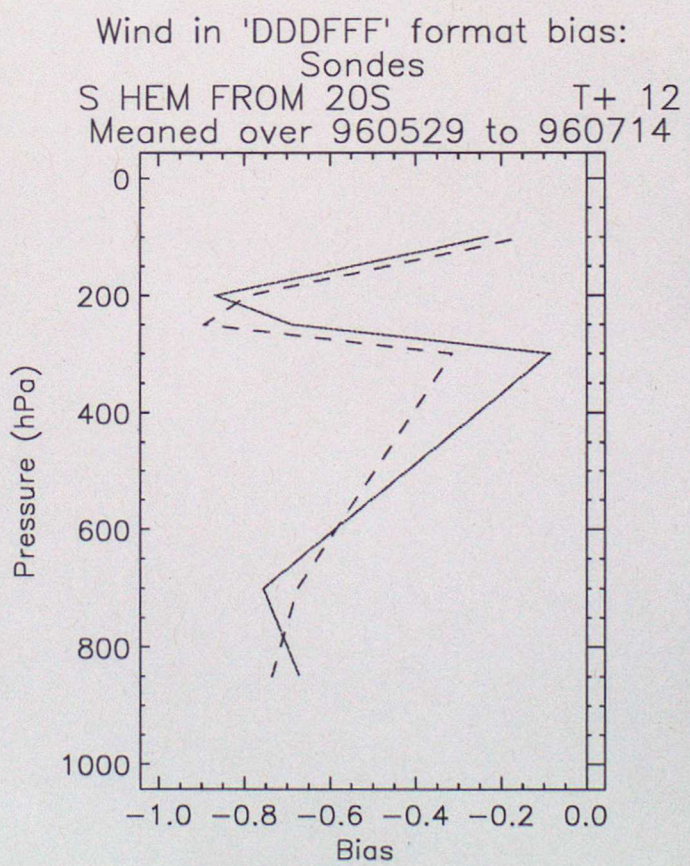
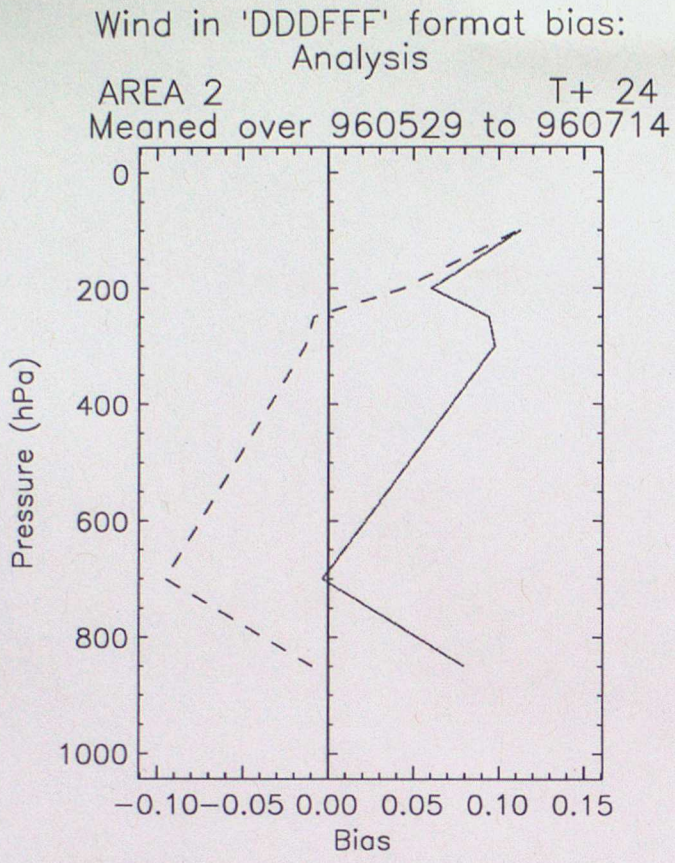
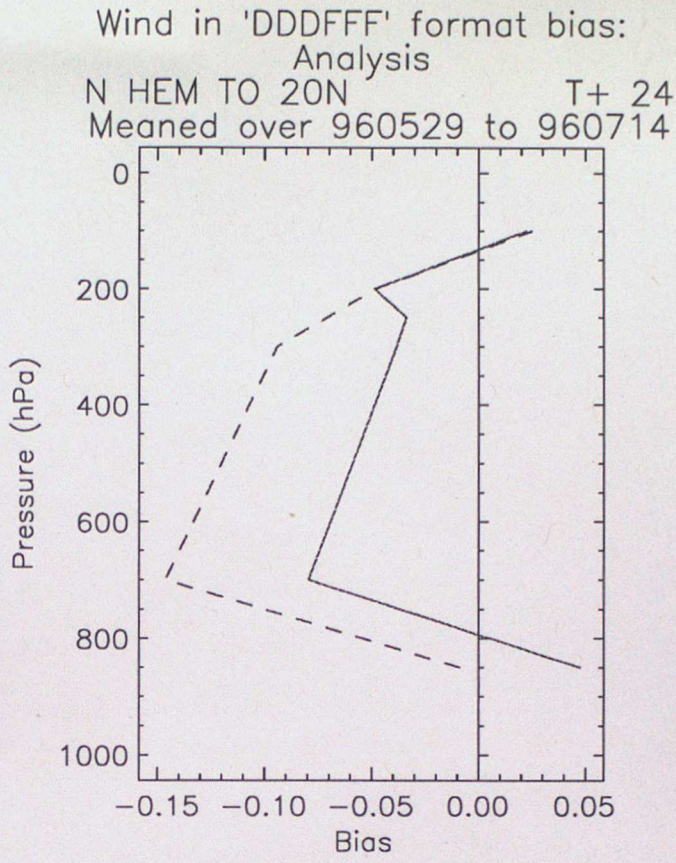
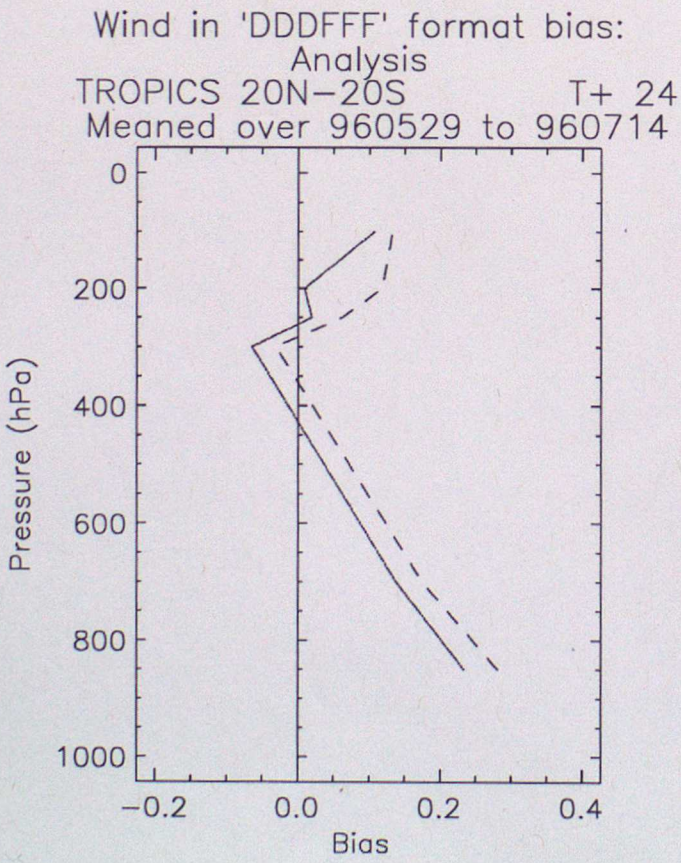

Wind in 'DDDFFF' format bias:
Sondes
S HEM FROM 20S T+ 12
Meaned over 960529 to 960714
Pressure (hPa)
0
200
400
600
800
1000
-1.0 -0.8 -0.6 -0.4 -0.2 0.0
Bias

FIGURE 4. 25


Wind in 'DDDFFF' format bias:
Analysis
AREA 2
T+ 24
Meaned over 960529 to 960714
Pressure (hPa)
0
200
400
600
800
1000
−0.10 −0.05 0.00 0.05 0.10 0.15
Bias


Wind in 'DDDFFF' format bias:
Analysis
N HEM TO 20N
T+ 24
Meaned over 960529 to 960714
Pressure (hPa)
0
200
400
600
800
1000
−0.15 −0.10 −0.05 0.00 0.05
Bias


Wind in 'DDDFFF' format bias:
Analysis
TROPICS 20N−20S
T+ 24
Meaned over 960529 to 960714
Pressure (hPa)
0
200
400
600
800
1000
−0.2 0.0 0.2 0.4
Bias

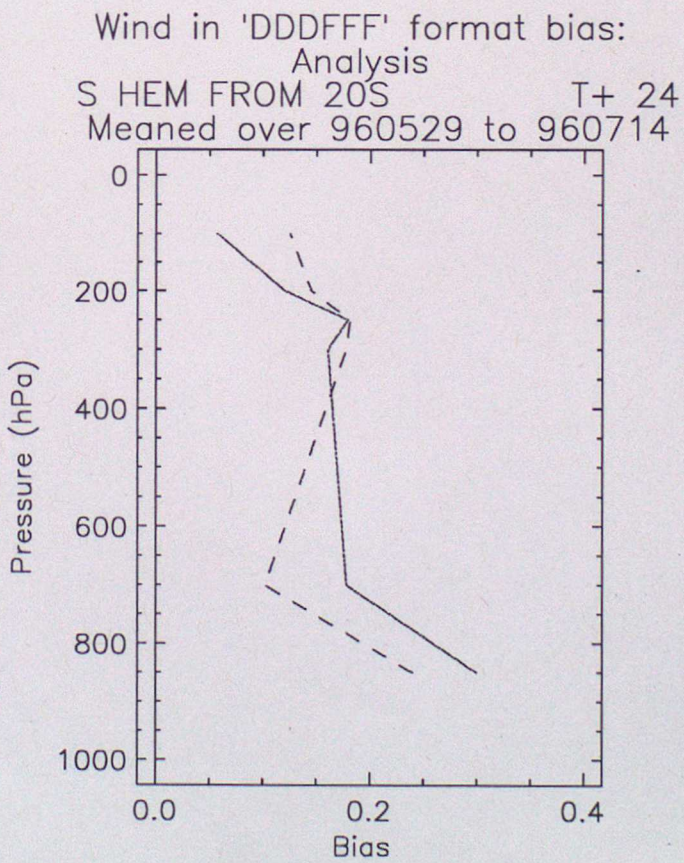
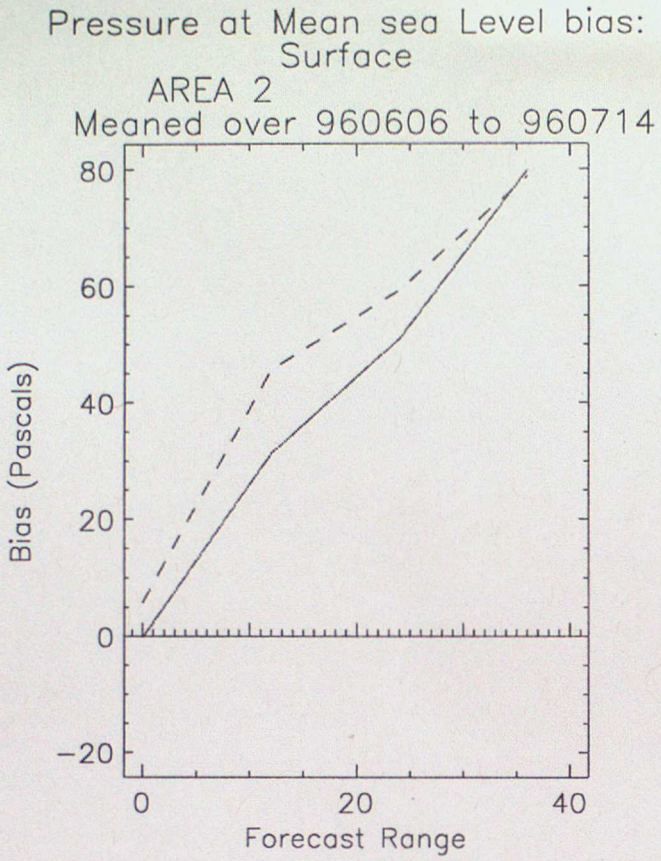
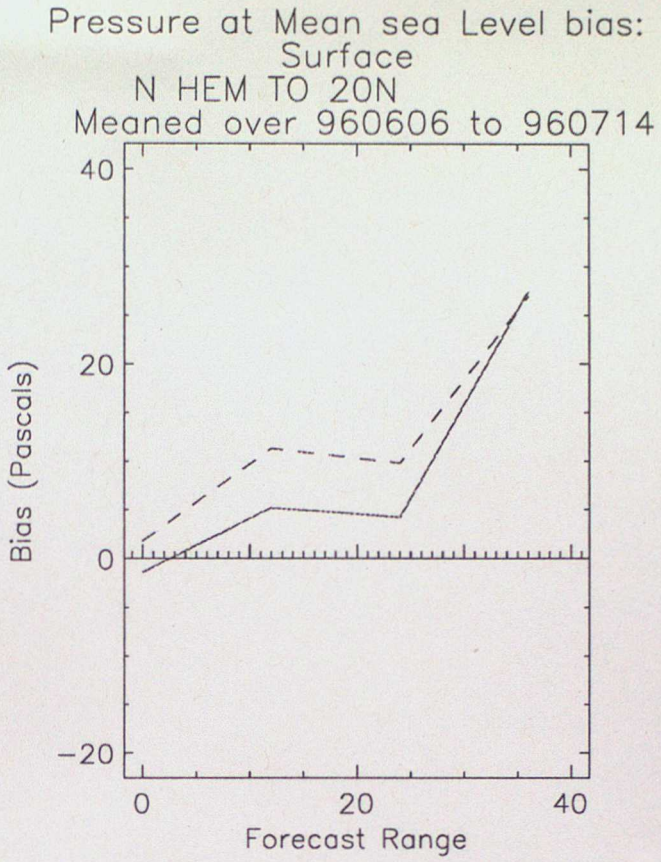
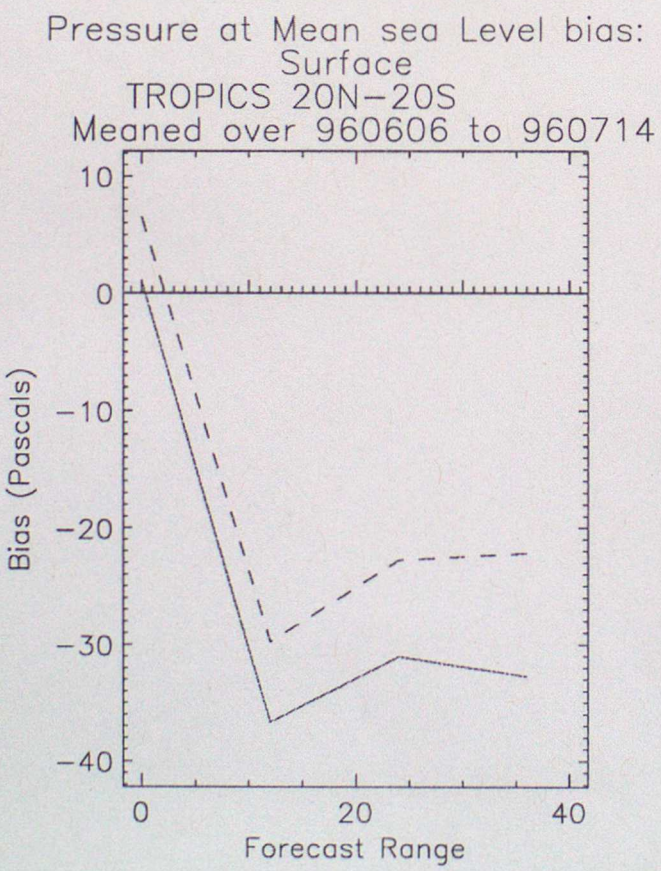

Wind in 'DDDFFF' format bias:
Analysis
S HEM FROM 20S
T+ 24
Meaned over 960529 to 960714
Pressure (hPa)
0
200
400
600
800
1000
0.0 0.2 0.4
Bias

FIGURE 4. 26


Pressure at Mean sea Level bias:
Surface
AREA 2
Meaned over 960606 to 960714
Bias (Pascals)
80
60
40
20
0
−20
0
20
40
Forecast Range


Pressure at Mean sea Level bias:
Surface
N HEM TO 20N
Meaned over 960606 to 960714
Bias (Pascals)
40
20
0
−20
0
20
40
Forecast Range


Pressure at Mean sea Level bias:
Surface
TROPICS 20N−20S
Meaned over 960606 to 960714
Bias (Pascals)
10
0
−10
−20
−30
−40
0
20
40
Forecast Range

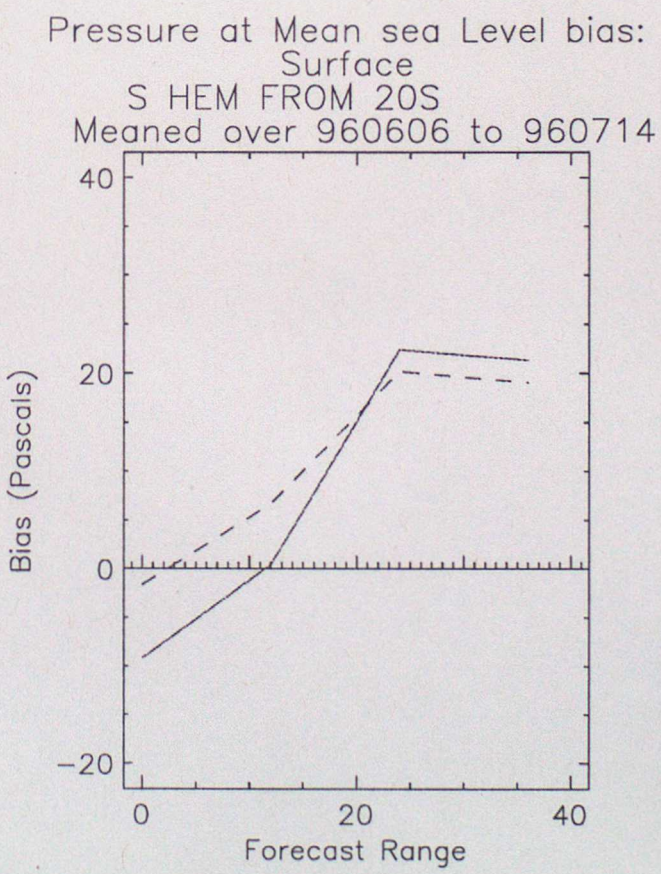
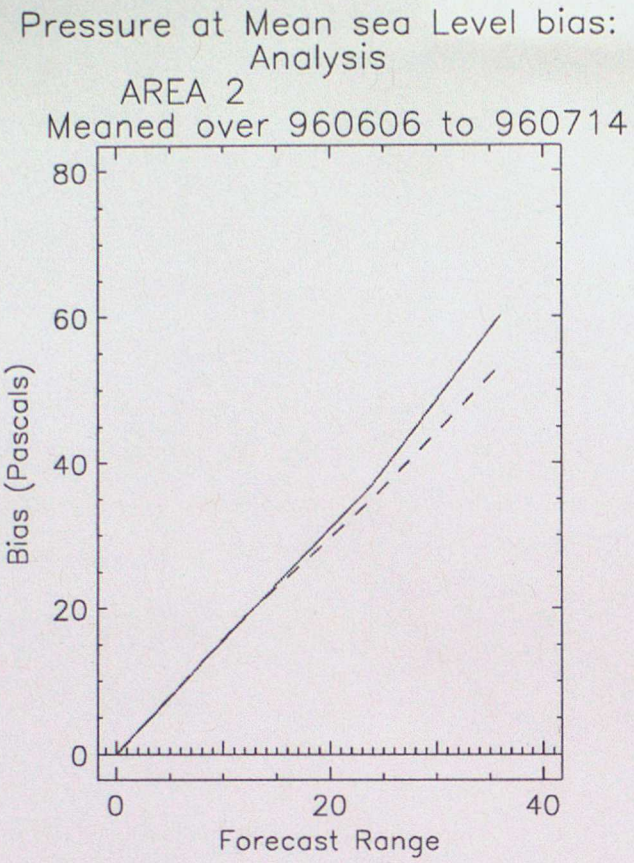
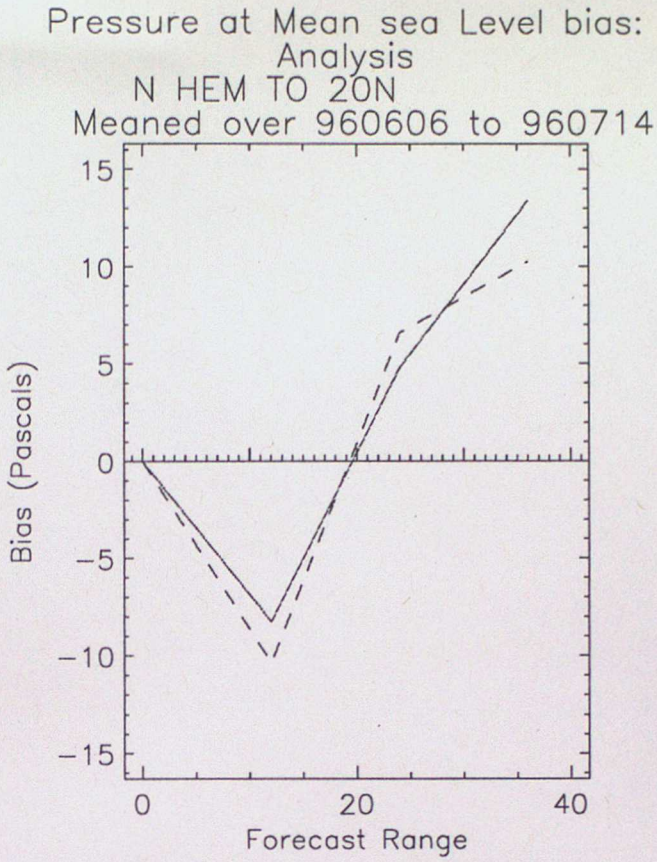
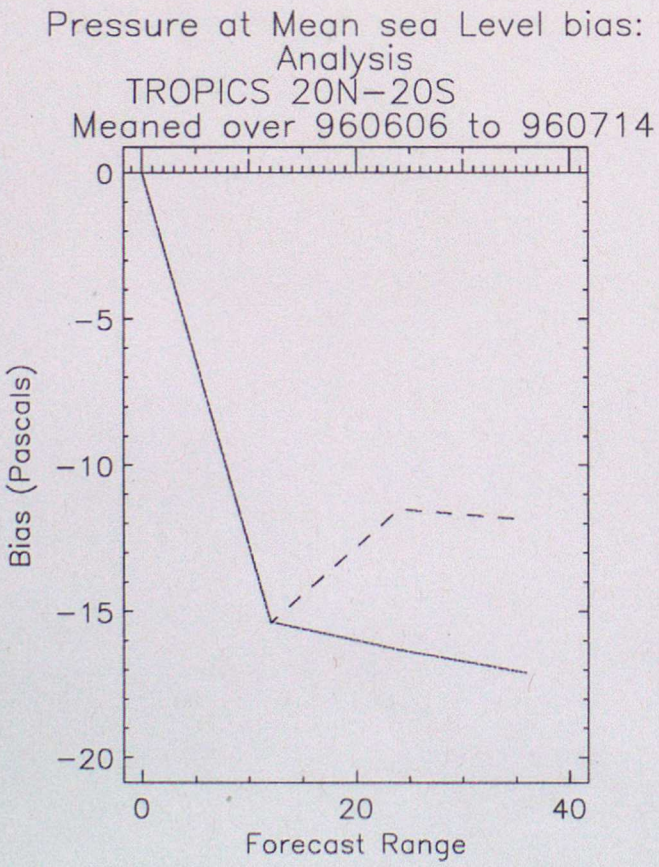

Pressure at Mean sea Level bias:
Surface
S HEM FROM 20S
Meaned over 960606 to 960714
Bias (Pascals)
40
20
0
−20
0
20
40
Forecast Range

FIGURE 4. 27


Pressure at Mean sea Level bias:
Analysis
AREA 2
Meaned over 960606 to 960714
Bias (Pascals)
80
60
40
20
0
0
20
40
Forecast Range


Pressure at Mean sea Level bias:
Analysis
N HEM TO 20N
Meaned over 960606 to 960714
Bias (Pascals)
15
10
5
0
−5
−10
−15
0
20
40
Forecast Range


Pressure at Mean sea Level bias:
Analysis
TROPICS 20N−20S
Meaned over 960606 to 960714
Bias (Pascals)
0
−5
−10
−15
−20
0
20
40
Forecast Range

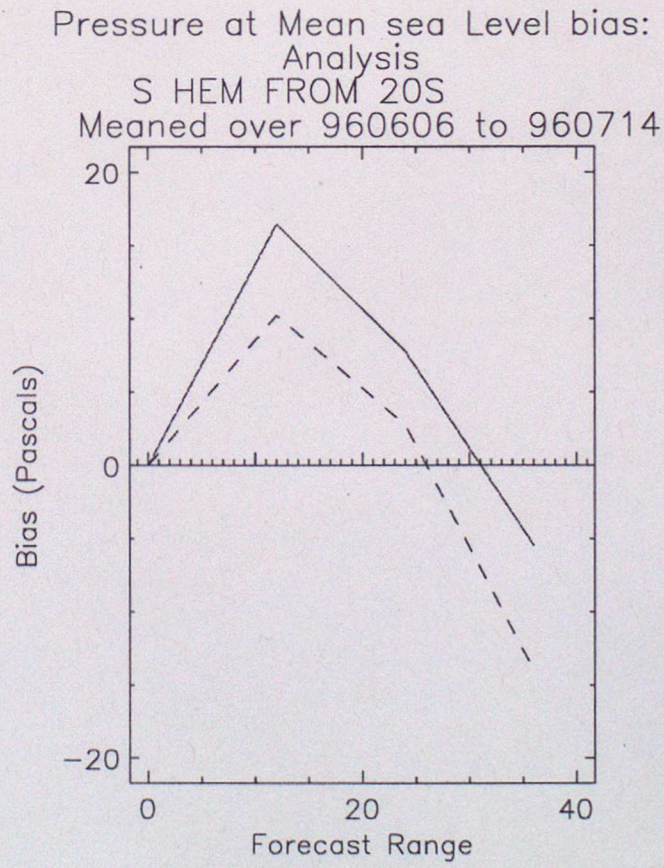
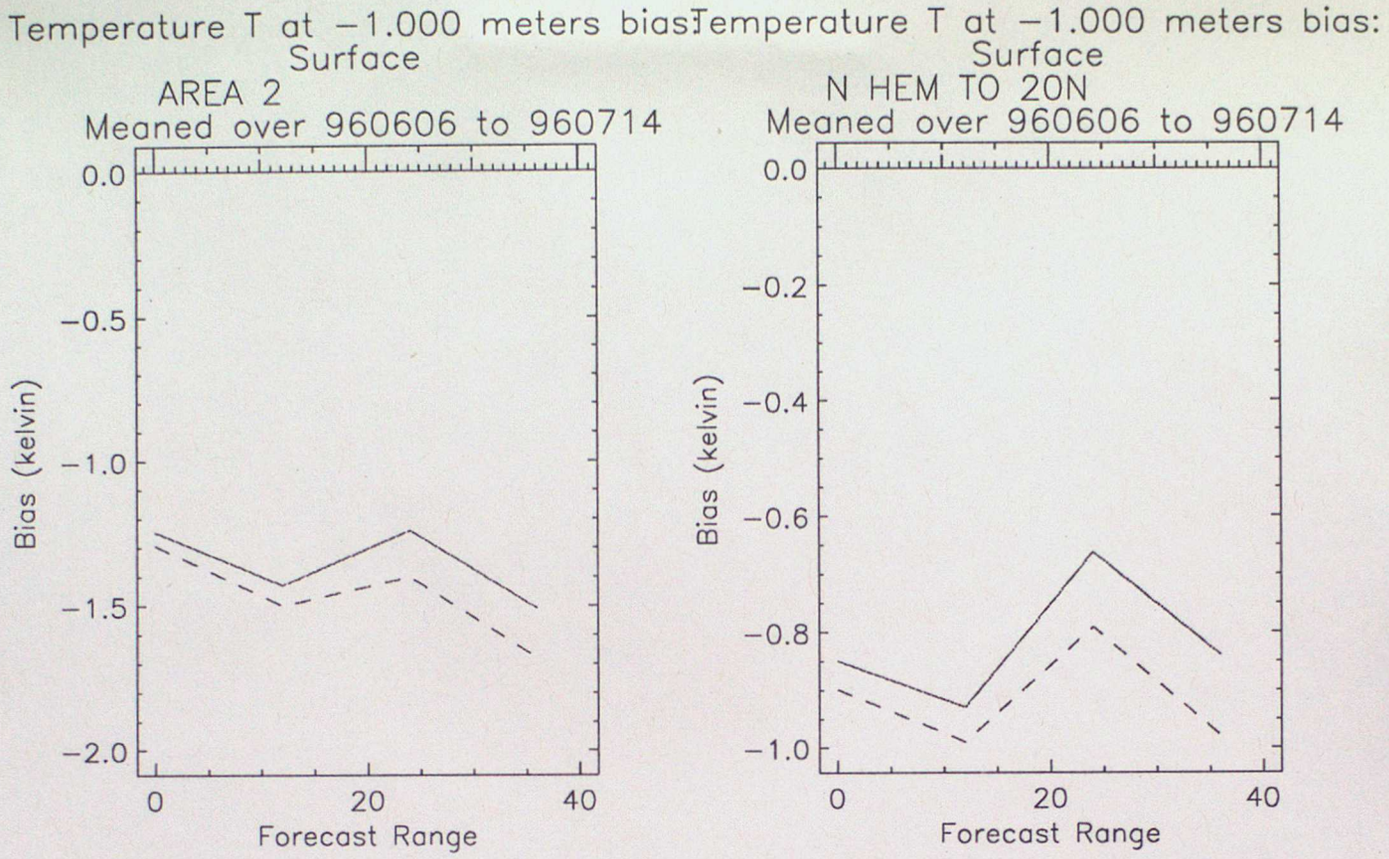

Pressure at Mean sea Level bias:
Analysis
S HEM FROM 20S
Meaned over 960606 to 960714
Bias (Pascals)
20
0
−20
0
20
40
Forecast Range

FIGURE 4. 28


Temperature T at −1.000 meters bias
Surface
AREA 2
Meaned over 960606 to 960714
Bias (kelvin)
0.0
−0.5
−1.0
−1.5
−2.0
0
20
40
Forecast Range
Temperature T at −1.000 meters bias:
Surface
N HEM TO 20N
Meaned over 960606 to 960714
Bias (kelvin)
0.0
−0.2
−0.4
−0.6
−0.8
−1.0
0
20
40
Forecast Range

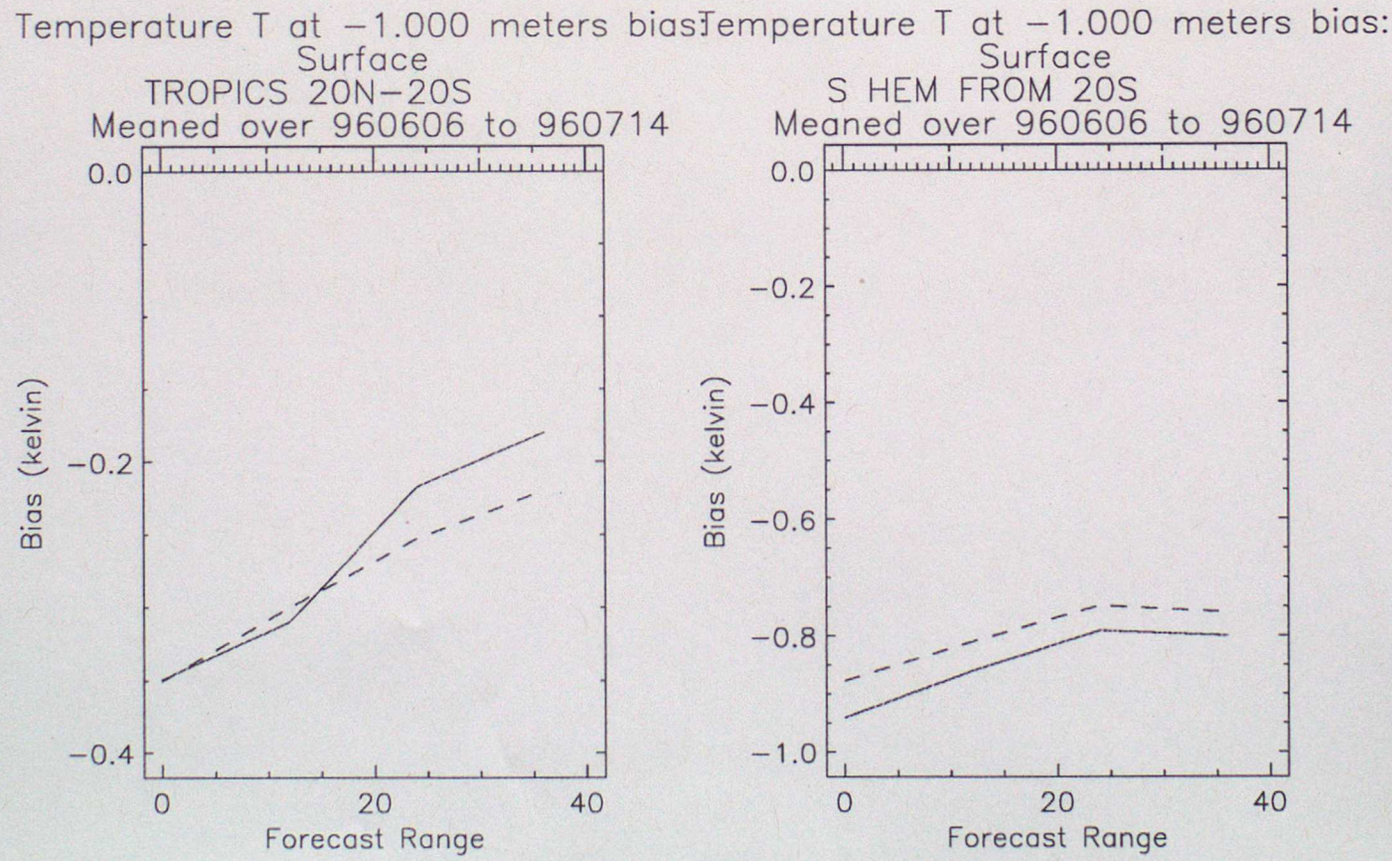
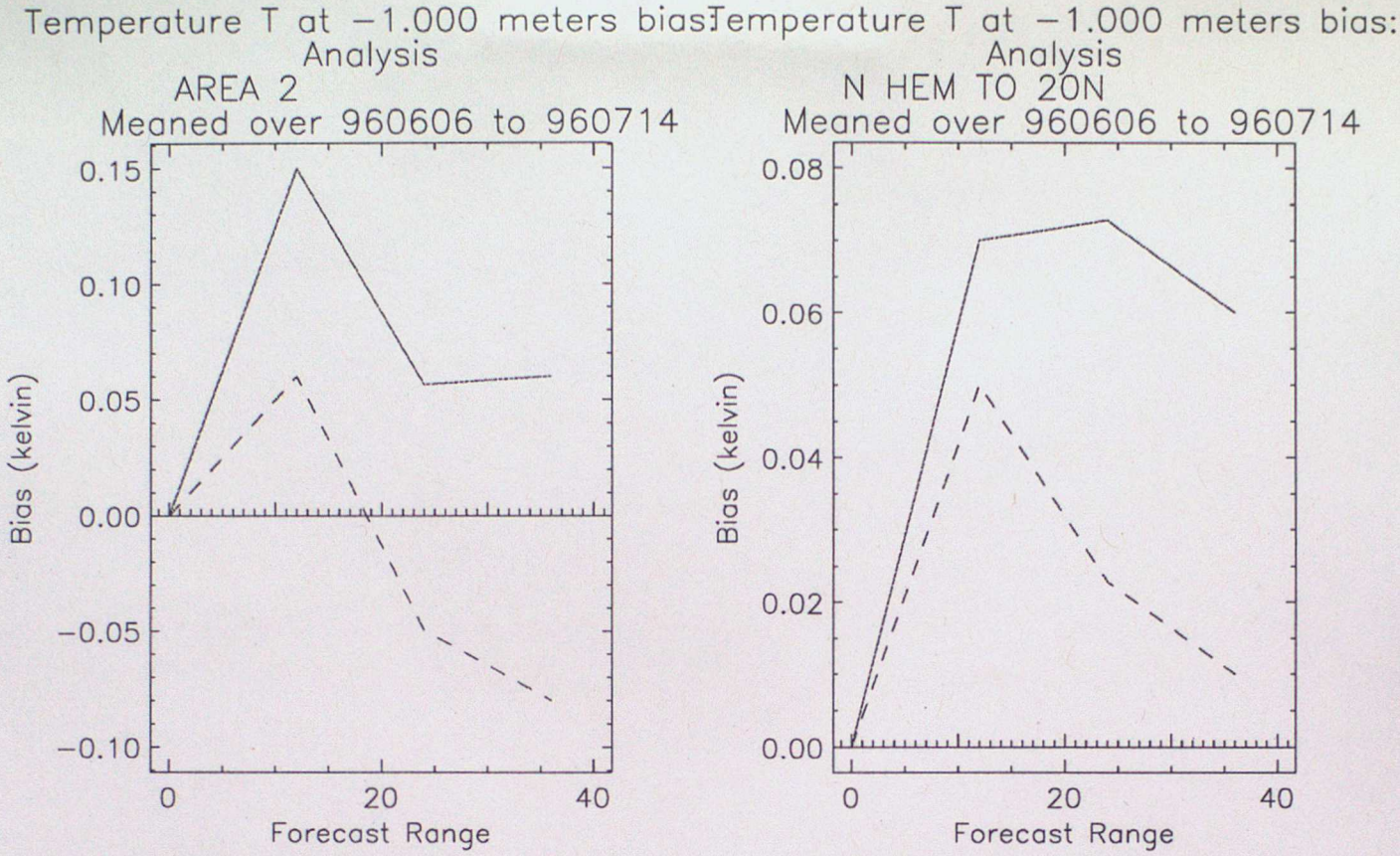

Temperature T at −1.000 meters bias
Surface
TROPICS 20N−20S
Meaned over 960606 to 960714
Bias (kelvin)
0.0
−0.2
−0.4
0
20
40
Forecast Range
Temperature T at −1.000 meters bias:
Surface
S HEM FROM 20S
Meaned over 960606 to 960714
Bias (kelvin)
0.0
−0.2
−0.4
−0.6
−0.8
−1.0
0
20
40
Forecast Range

FIGURE 4. 29


Temperature T at −1.000 meters bias: Analysis
AREA 2
Meaned over 960606 to 960714
Bias (kelvin)
0.15
0.10
0.05
0.00
−0.05
−0.10
0
20
40
Forecast Range
Temperature T at −1.000 meters bias: Analysis
N HEM TO 20N
Meaned over 960606 to 960714
Bias (kelvin)
0.08
0.06
0.04
0.02
0.00
0
20
40
Forecast Range

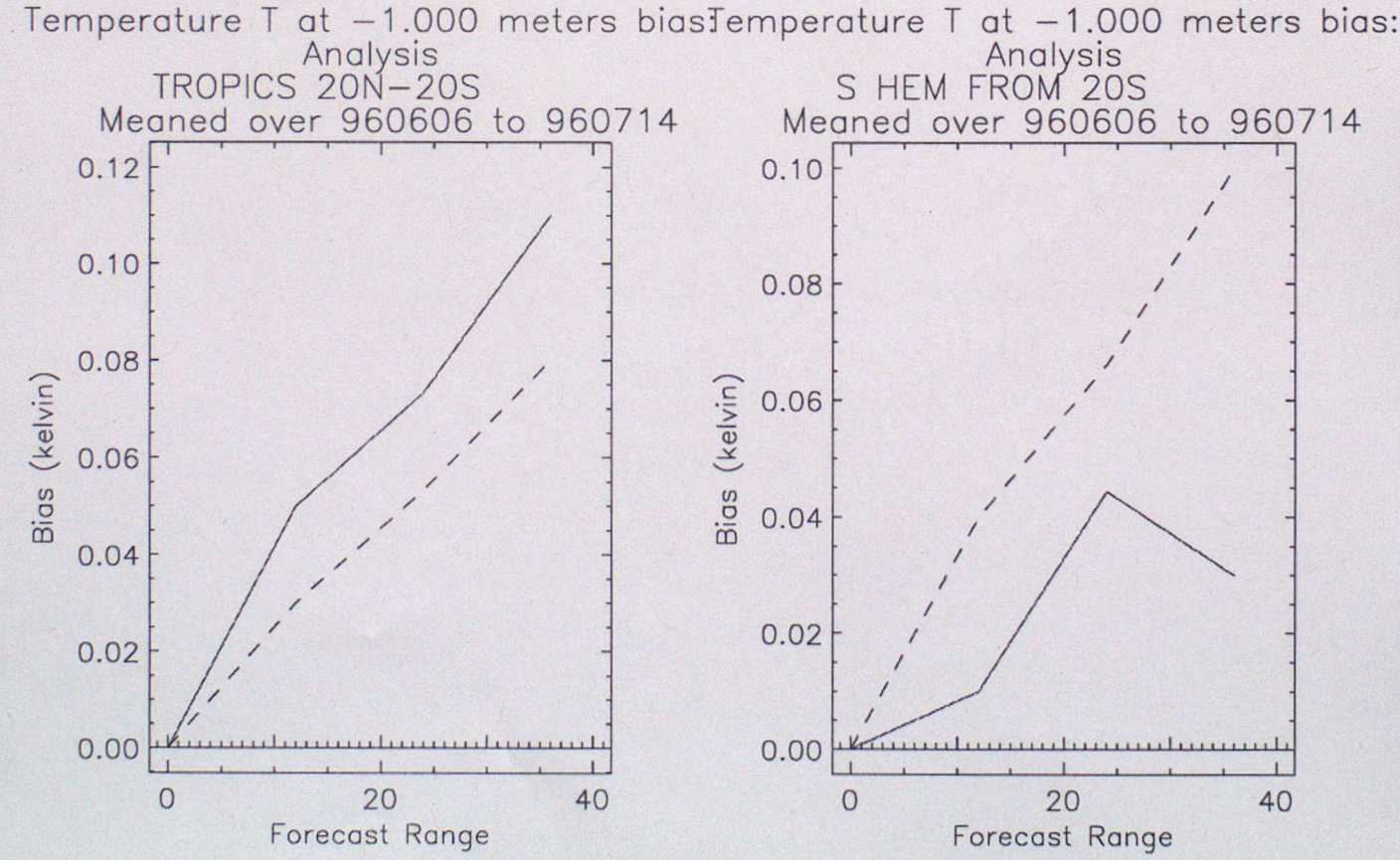

Temperature T at −1.000 meters bias: Analysis
TROPICS 20N−20S
Meaned over 960606 to 960714
Bias (kelvin)
0.12
0.10
0.08
0.06
0.04
0.02
0.00
0
20
40
Forecast Range
Temperature T at −1.000 meters bias: Analysis
S HEM FROM 20S
Meaned over 960606 to 960714
Bias (kelvin)
0.10
0.08
0.06
0.04
0.02
0.00
0
20
40
Forecast Range

FIGURE 4. 30

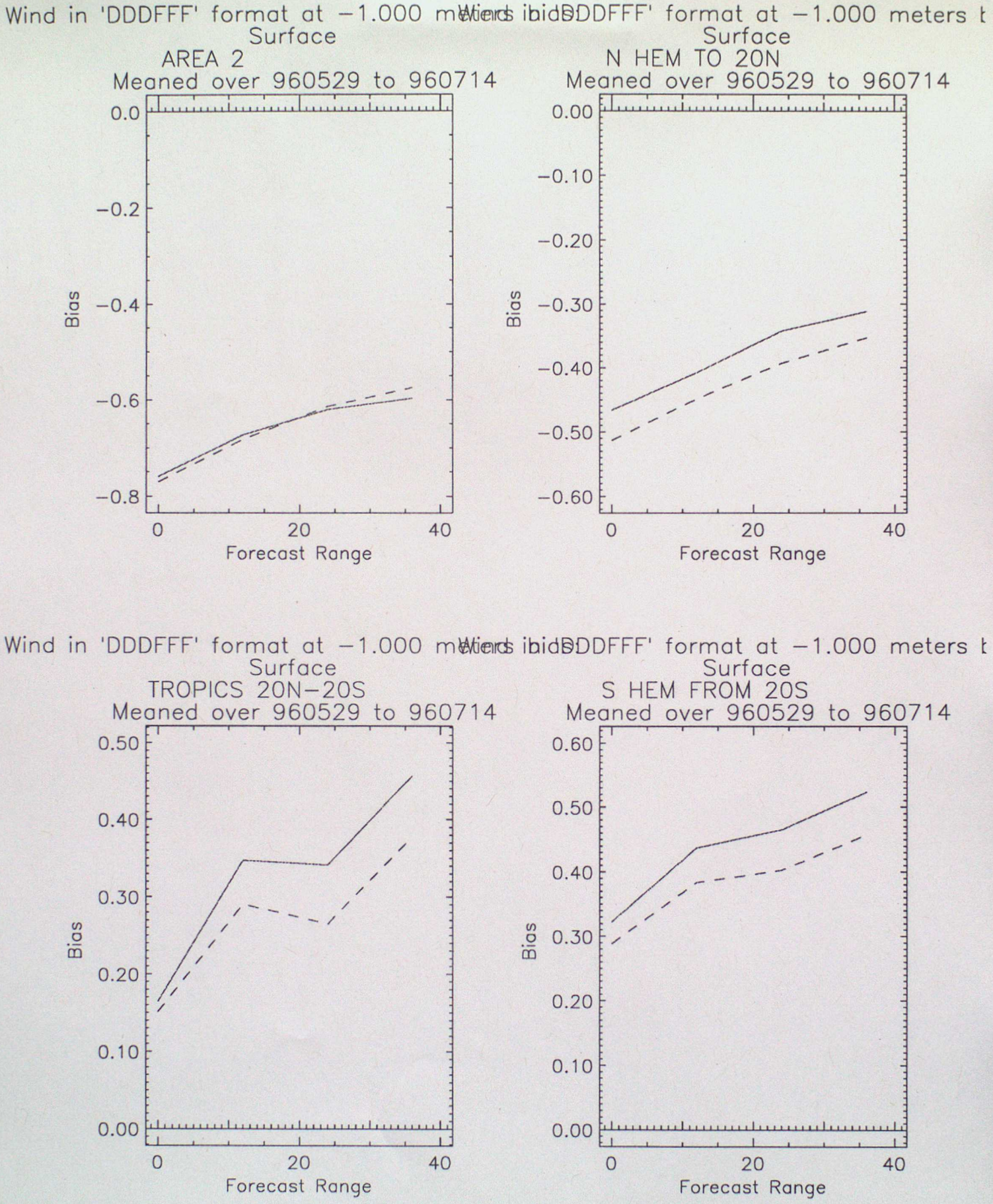
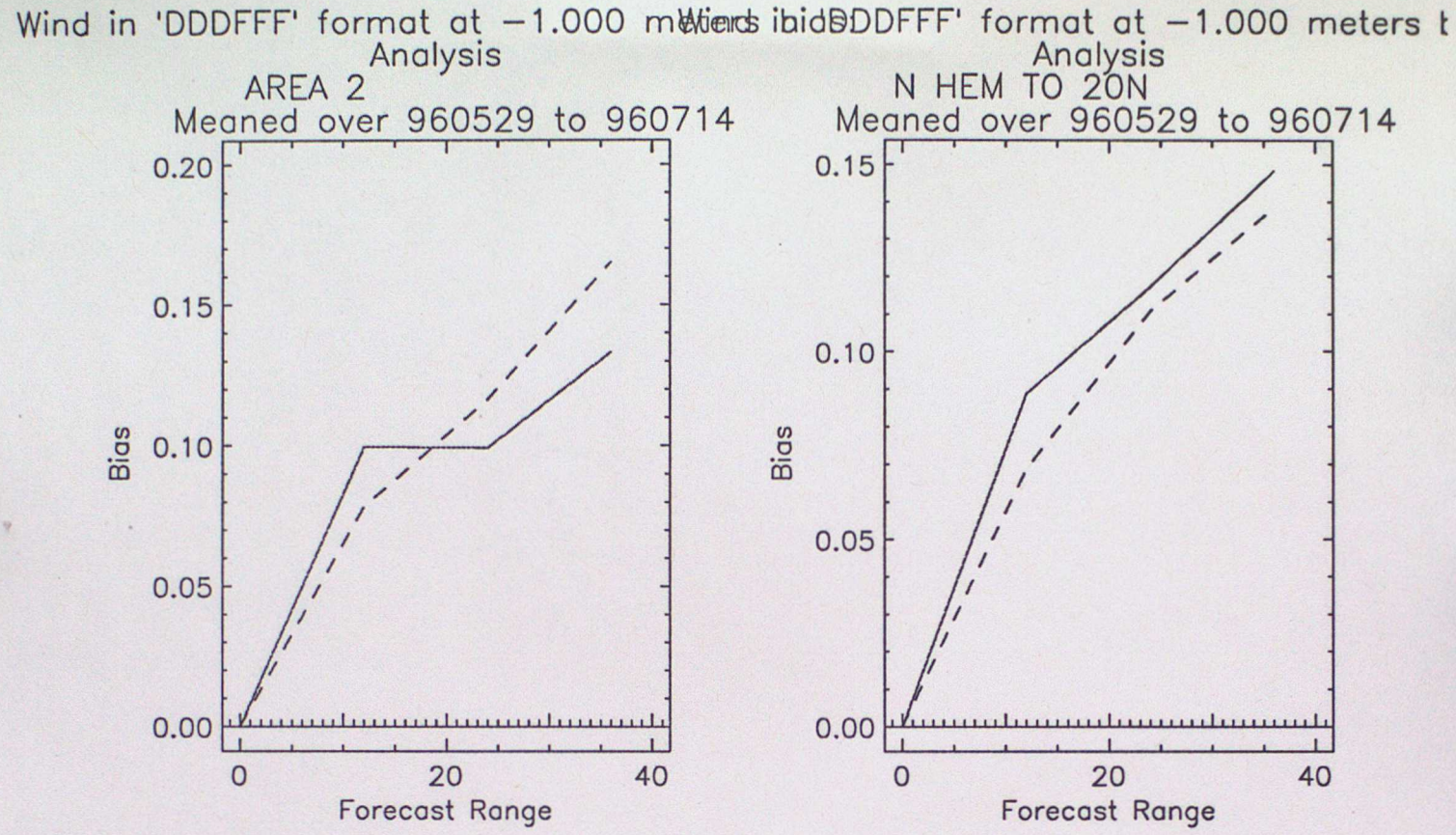

Wind in 'DDDFFF' format at −1.000 meters
Surface
AREA 2
Meaned over 960529 to 960714
Bias
0.0
−0.2
−0.4
−0.6
−0.8
0
20
40
Forecast Range
Wind in 'DDDFFF' format at −1.000 meters
Surface
N HEM TO 20N
Meaned over 960529 to 960714
Bias
0.00
−0.10
−0.20
−0.30
−0.40
−0.50
−0.60
0
20
40
Forecast Range
Wind in 'DDDFFF' format at −1.000 meters
Surface
TROPICS 20N−20S
Meaned over 960529 to 960714
Bias
0.50
0.40
0.30
0.20
0.10
0.00
0
20
40
Forecast Range
Wind in 'DDDFFF' format at −1.000 meters
Surface
S HEM FROM 20S
Meaned over 960529 to 960714
Bias
0.60
0.50
0.40
0.30
0.20
0.10
0.00
0
20
40
Forecast Range

FIGURE 4. 31


Wind in 'DDDFFF' format at −1.000 meters
Analysis
AREA 2
Meaned over 960529 to 960714
Bias
0.20
0.15
0.10
0.05
0.00
0
20
40
Forecast Range
Wind in 'DDDFFF' format at −1.000 meters
Analysis
N HEM TO 20N
Meaned over 960529 to 960714
Bias
0.15
0.10
0.05
0.00
0
20
40
Forecast Range

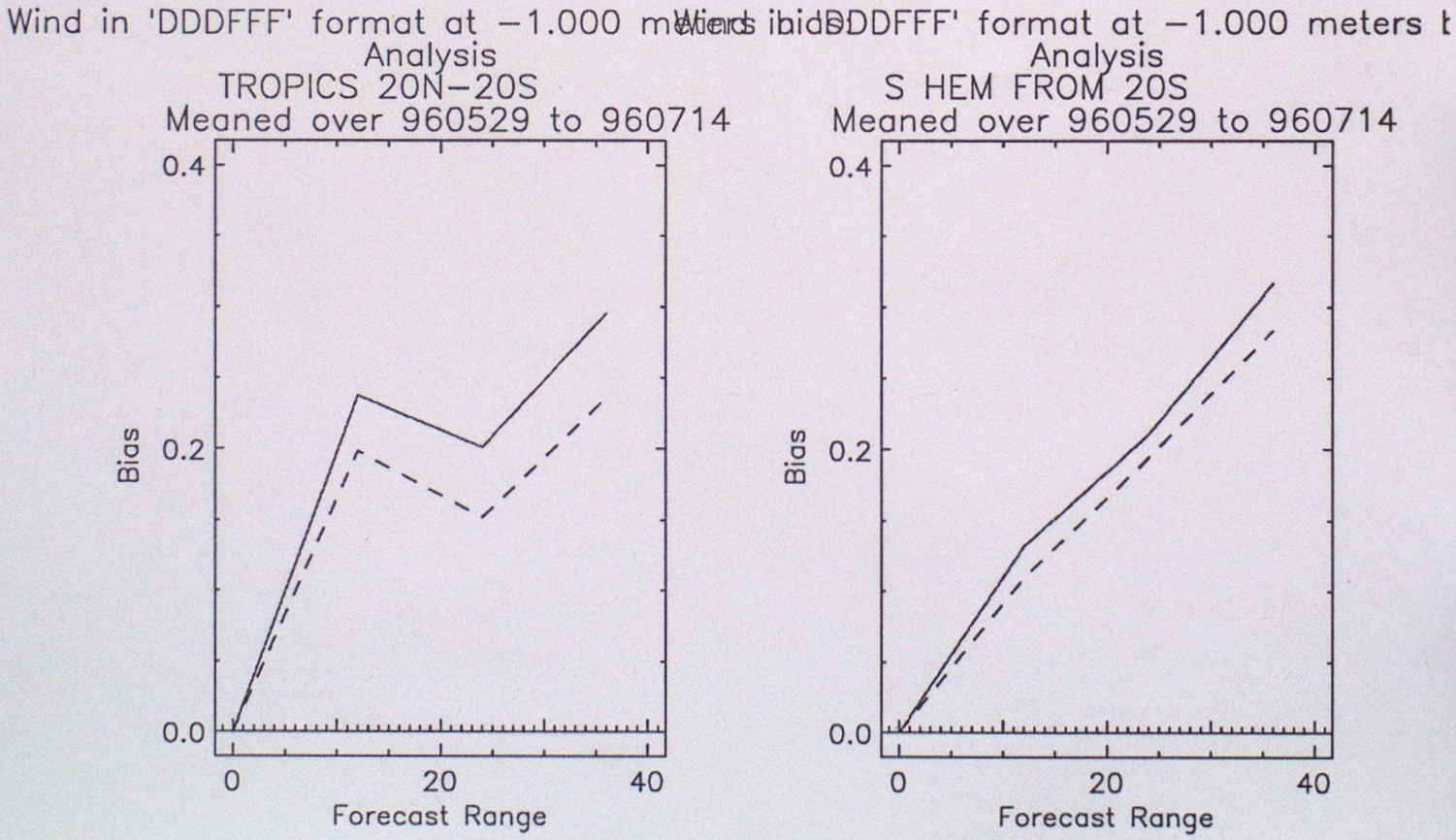
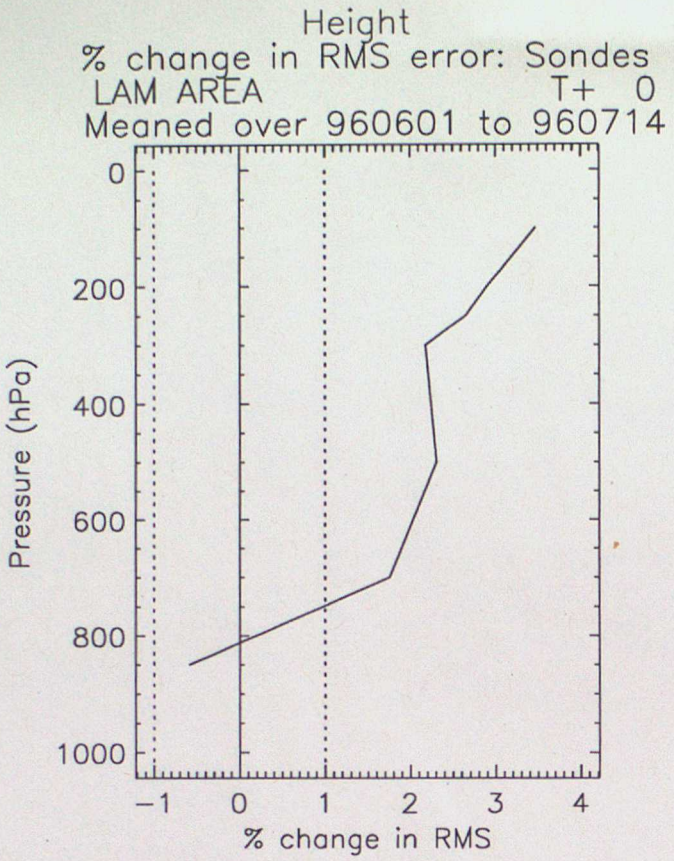
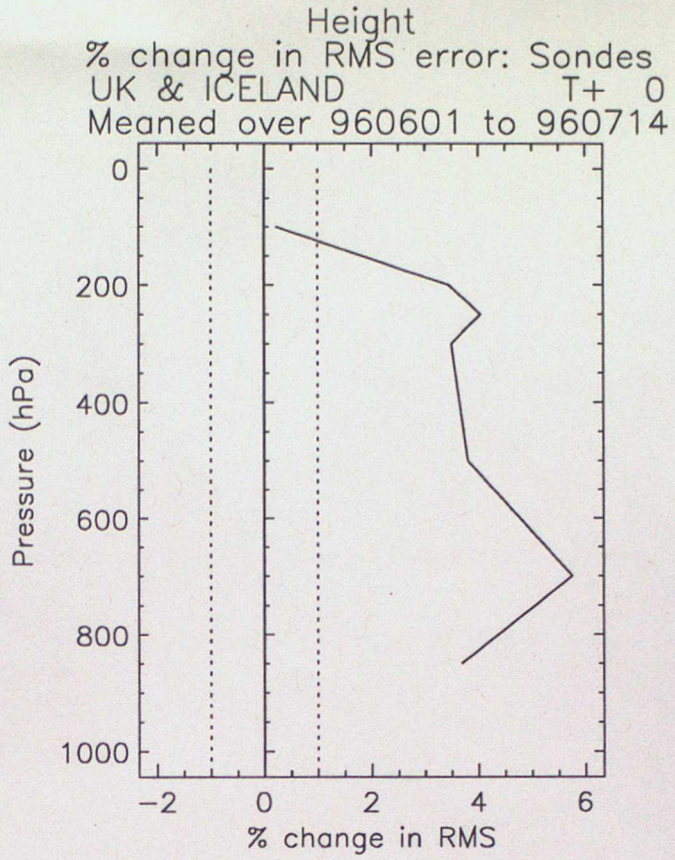
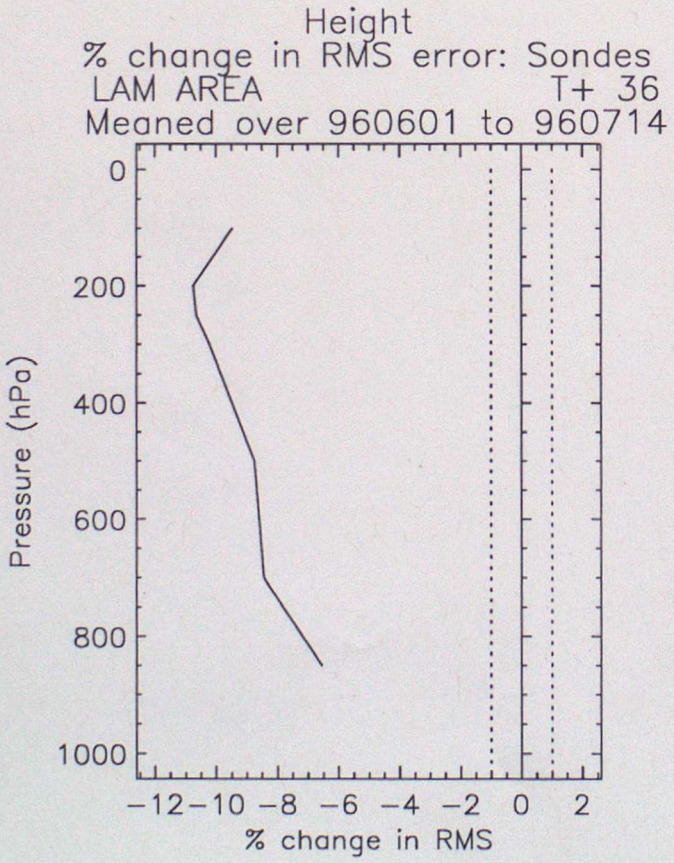

Wind in 'DDDFFF' format at −1.000 meters
Analysis
TROPICS 20N−20S
Meaned over 960529 to 960714
Bias
0.4
0.2
0.0
0
20
40
Forecast Range
Wind in 'DDDFFF' format at −1.000 meters
Analysis
S HEM FROM 20S
Meaned over 960529 to 960714
Bias
0.4
0.2
0.0
0
20
40
Forecast Range

FIGURE 4. 32


Height
% change in RMS error: Sondes
LAM AREA T+ 0
Meaned over 960601 to 960714
Pressure (hPa)
0
200
400
600
800
1000
−1 0 1 2 3 4
% change in RMS


Height
% change in RMS error: Sondes
UK & ICELAND T+ 0
Meaned over 960601 to 960714
Pressure (hPa)
0
200
400
600
800
1000
−2 0 2 4 6
% change in RMS


Height
% change in RMS error: Sondes
LAM AREA T+ 36
Meaned over 960601 to 960714
Pressure (hPa)
0
200
400
600
800
1000
−12 −10 −8 −6 −4 −2 0 2
% change in RMS

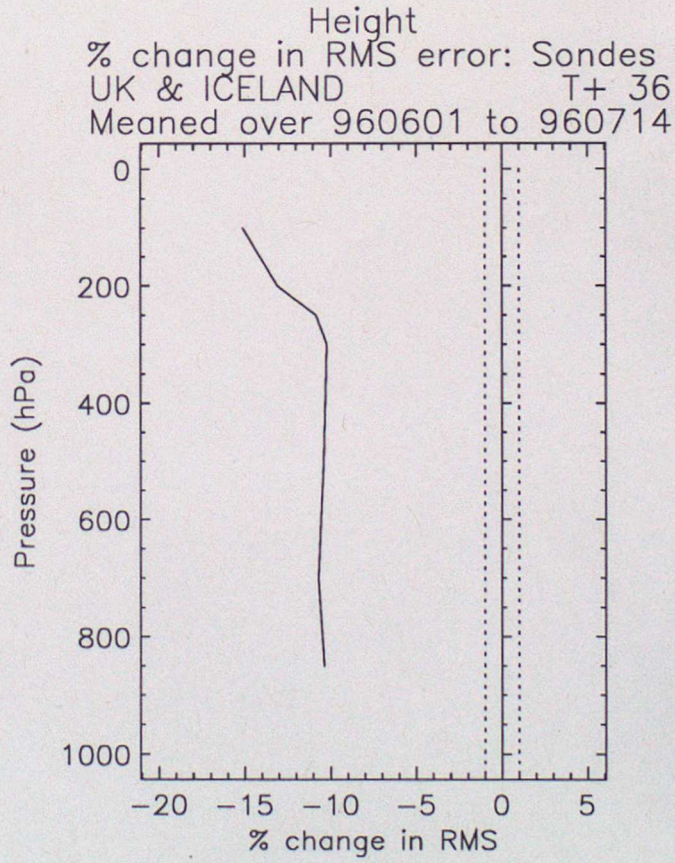

Height
% change in RMS error: Sondes
UK & ICELAND T+ 36
Meaned over 960601 to 960714
Pressure (hPa)
0
200
400
600
800
1000
−20 −15 −10 −5 0 5
% change in RMS

FIGURE 4. 33

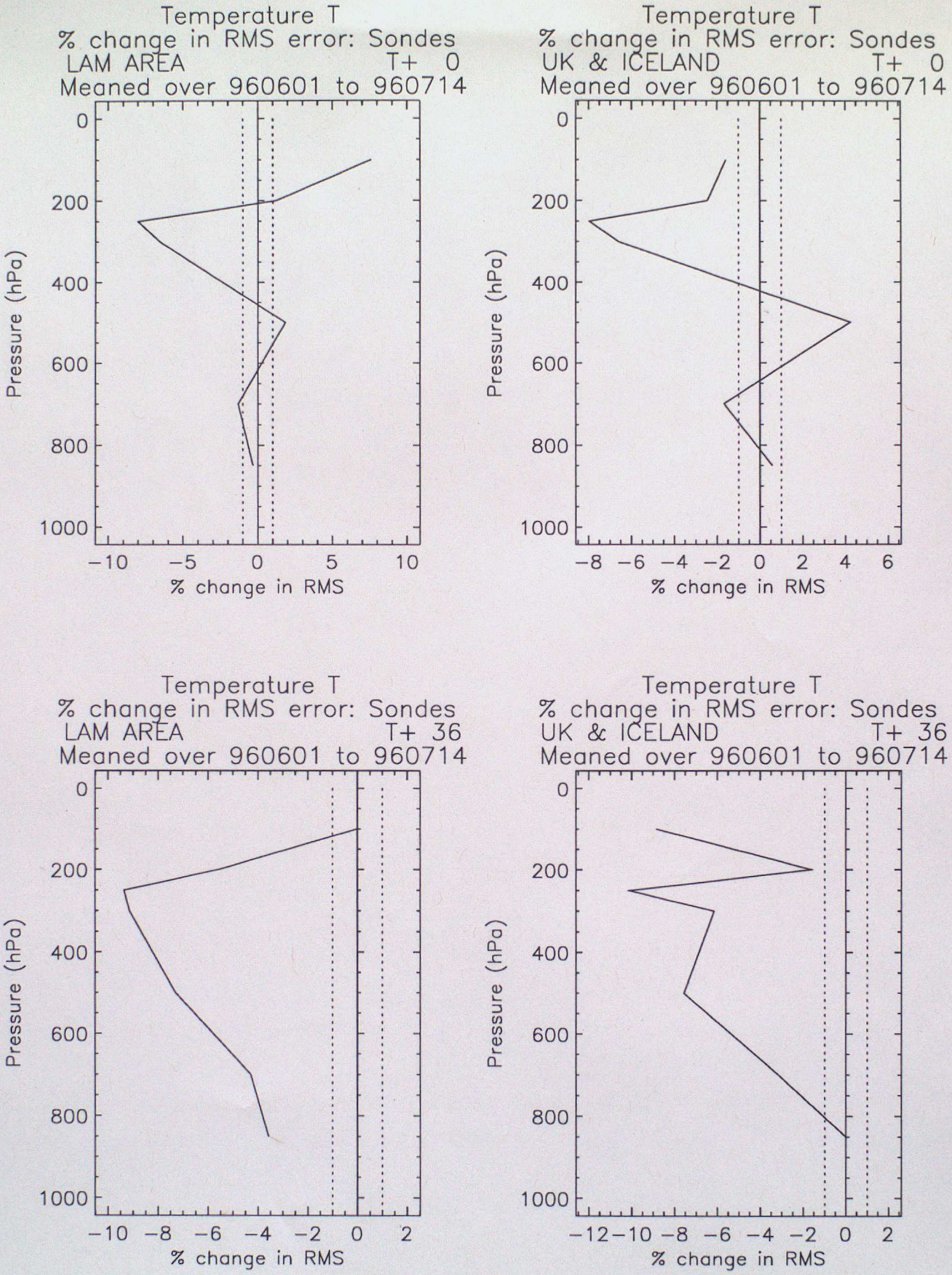
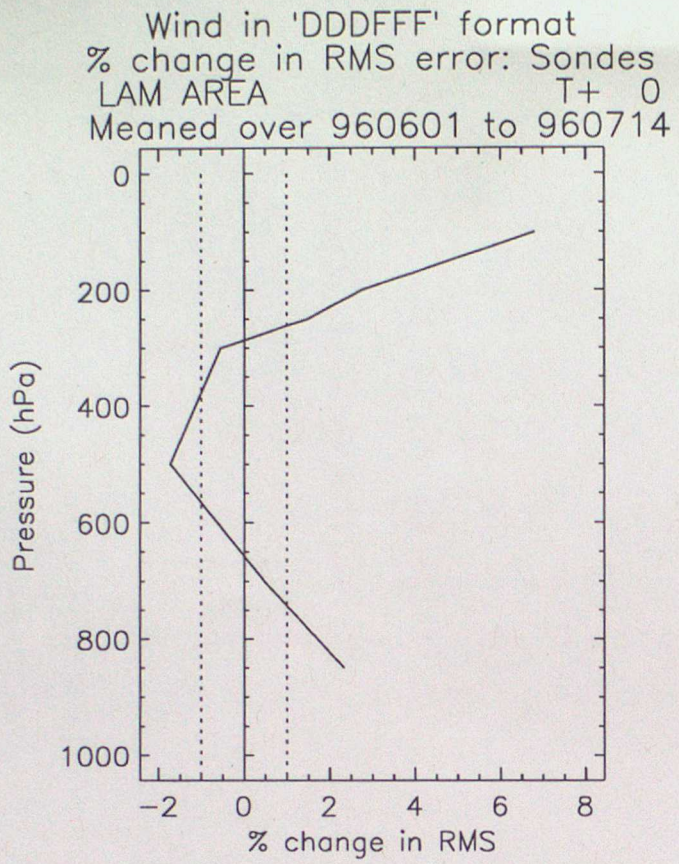
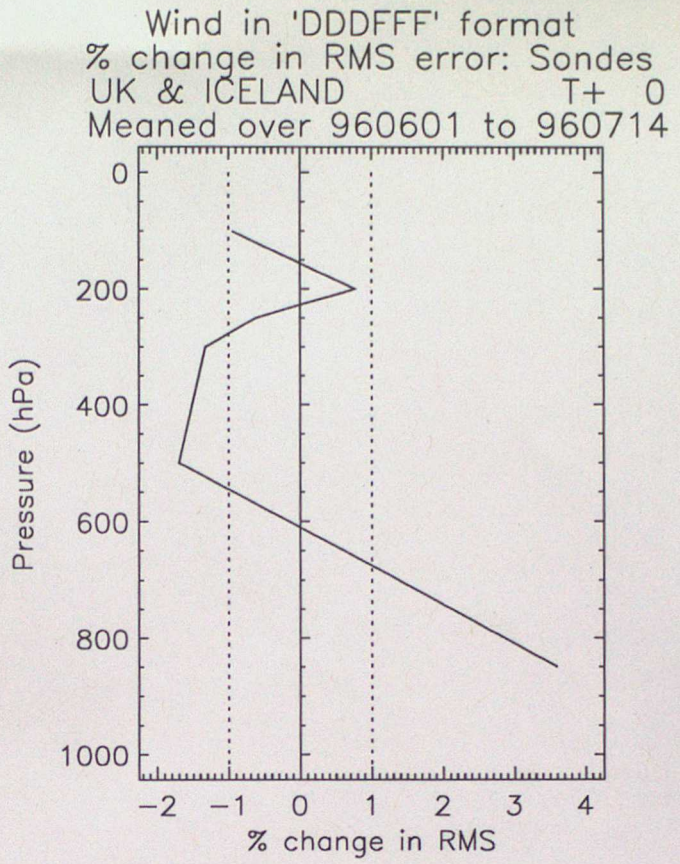
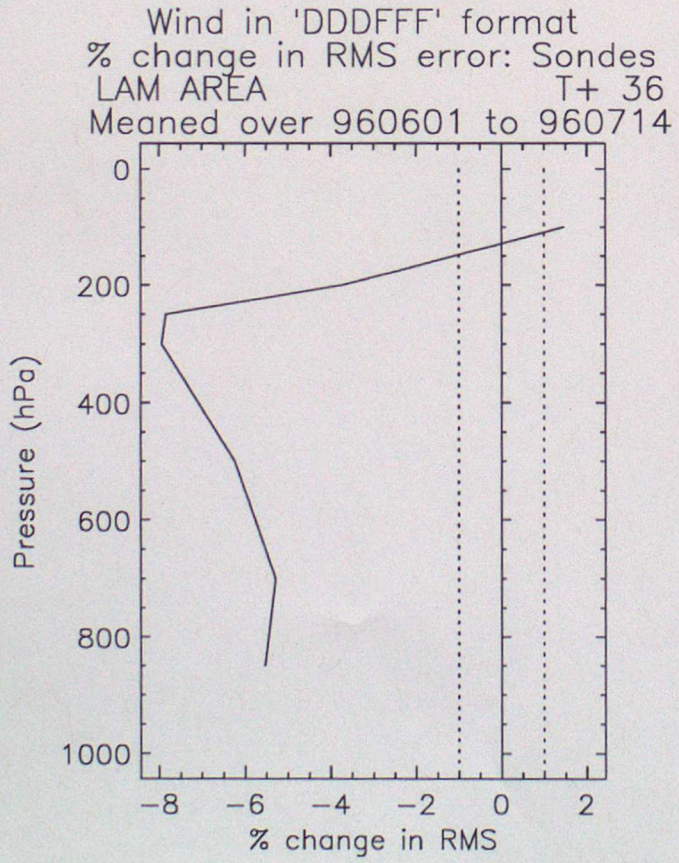

Temperature T
% change in RMS error: Sondes
LAM AREA T+ 0
Meaned over 960601 to 960714
Pressure (hPa)
0
200
400
600
800
1000
−10 −5 0 5 10
% change in RMS
Temperature T
% change in RMS error: Sondes
UK & ICELAND T+ 0
Meaned over 960601 to 960714
Pressure (hPa)
0
200
400
600
800
1000
−8 −6 −4 −2 0 2 4 6
% change in RMS
Temperature T
% change in RMS error: Sondes
LAM AREA T+ 36
Meaned over 960601 to 960714
Pressure (hPa)
0
200
400
600
800
1000
−10 −8 −6 −4 −2 0 2
% change in RMS
Temperature T
% change in RMS error: Sondes
UK & ICELAND T+ 36
Meaned over 960601 to 960714
Pressure (hPa)
0
200
400
600
800
1000
−12 −10 −8 −6 −4 −2 0 2
% change in RMS

FIGURE 4. 34


Wind in 'DDDFFF' format
% change in RMS error: Sondes
LAM AREA T+ 0
Meaned over 960601 to 960714
Pressure (hPa)
0
200
400
600
800
1000
−2
0
2
4
6
8
% change in RMS


Wind in 'DDDFFF' format
% change in RMS error: Sondes
UK & ICELAND T+ 0
Meaned over 960601 to 960714
Pressure (hPa)
0
200
400
600
800
1000
−2
−1
0
1
2
3
4
% change in RMS


Wind in 'DDDFFF' format
% change in RMS error: Sondes
LAM AREA T+ 36
Meaned over 960601 to 960714
Pressure (hPa)
0
200
400
600
800
1000
−8
−6
−4
−2
0
2
% change in RMS

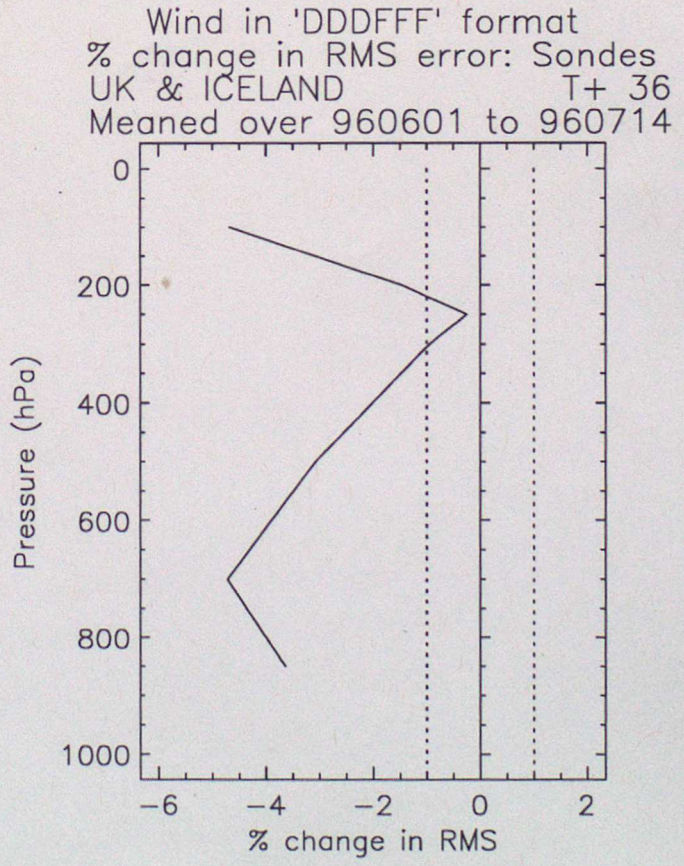
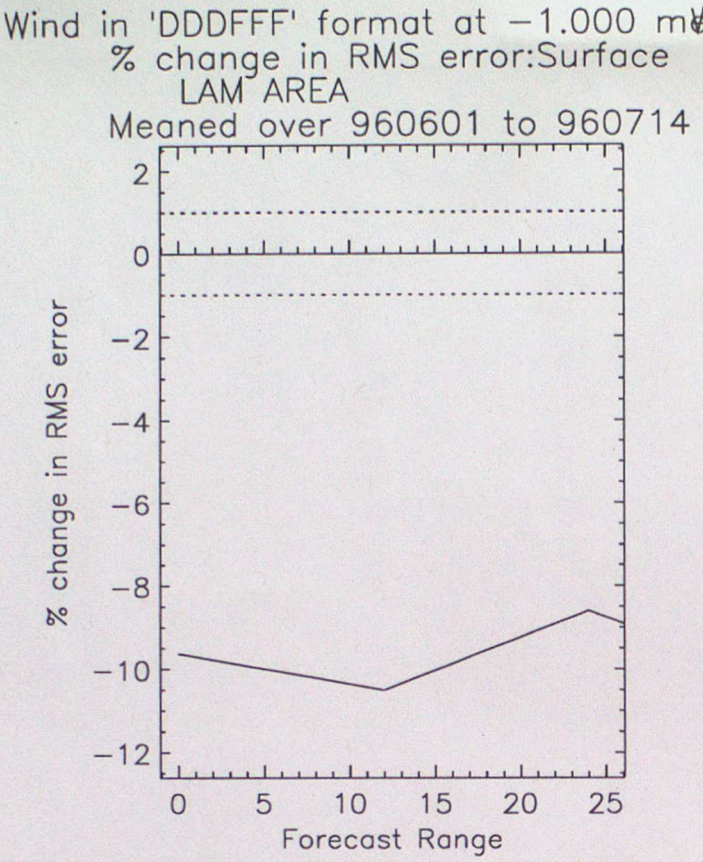
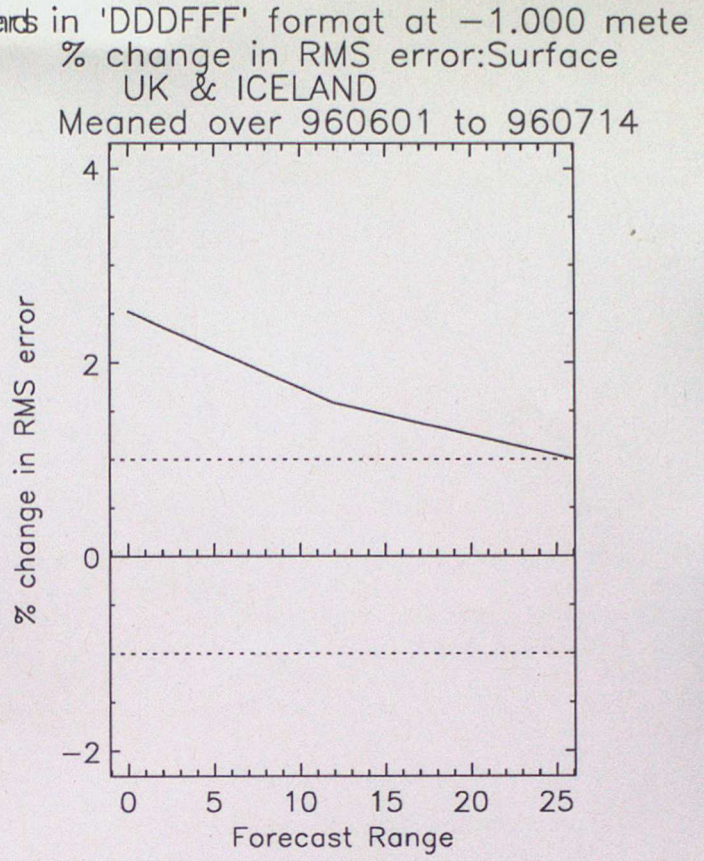
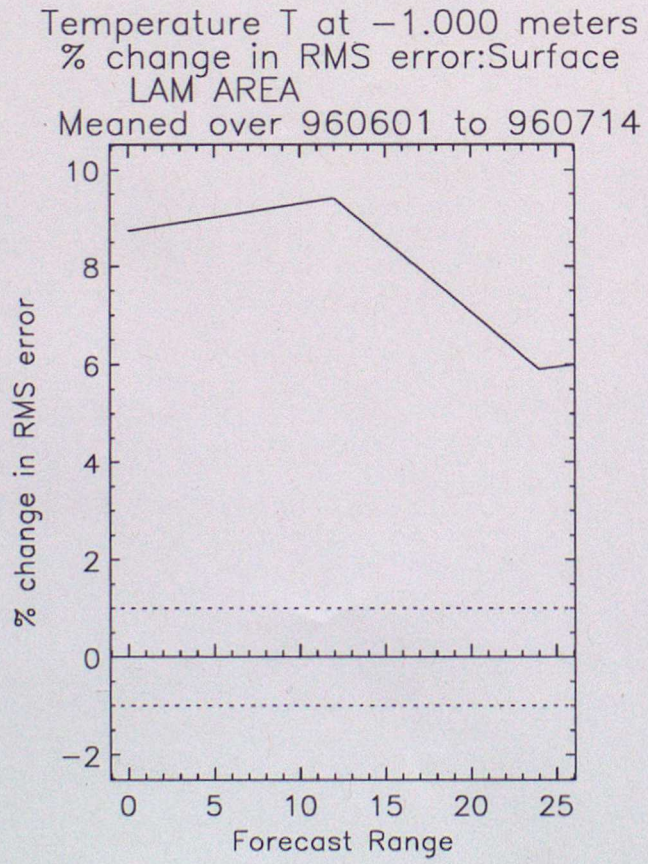

Wind in 'DDDFFF' format
% change in RMS error: Sondes
UK & ICELAND T+ 36
Meaned over 960601 to 960714
Pressure (hPa)
0
200
400
600
800
1000
−6
−4
−2
0
2
% change in RMS

FIGURE 4. 35


Wind in 'DDDFFF' format at −1.000 meters
% change in RMS error:Surface
LAM AREA
Meaned over 960601 to 960714
% change in RMS error
Forecast Range
2
0
−2
−4
−6
−8
−10
−12
0
5
10
15
20
25


Wind in 'DDDFFF' format at −1.000 mete
% change in RMS error:Surface
UK & ICELAND
Meaned over 960601 to 960714
% change in RMS error
Forecast Range
4
2
0
−2
0
5
10
15
20
25


Temperature T at −1.000 meters
% change in RMS error:Surface
LAM AREA
Meaned over 960601 to 960714
% change in RMS error
Forecast Range
10
8
6
4
2
0
−2
0
5
10
15
20
25

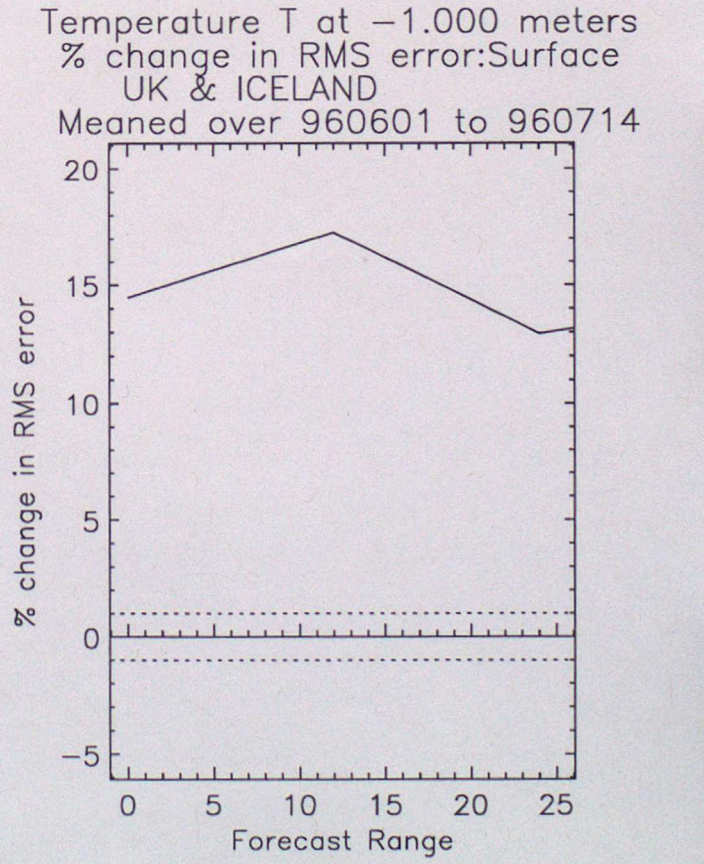
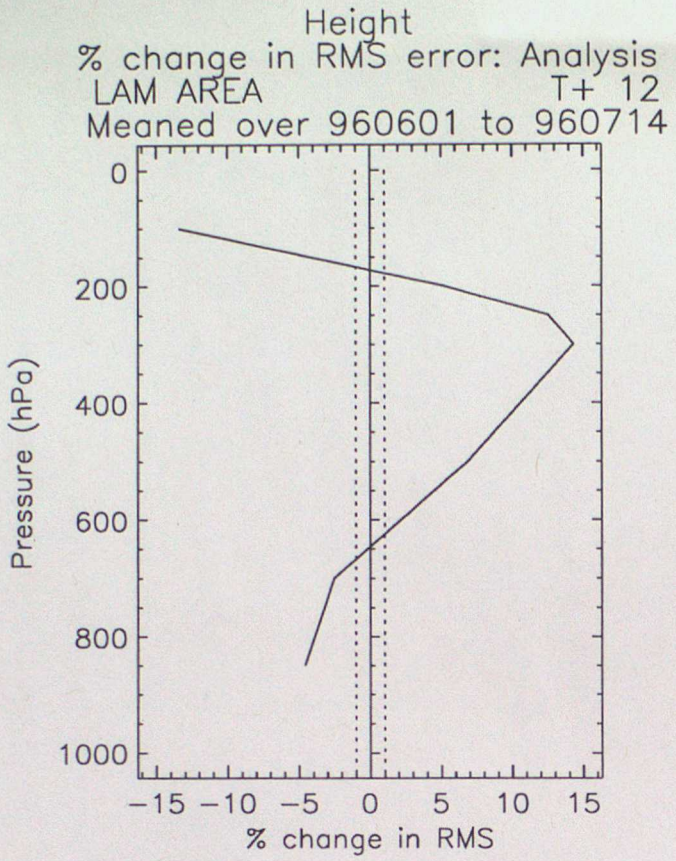
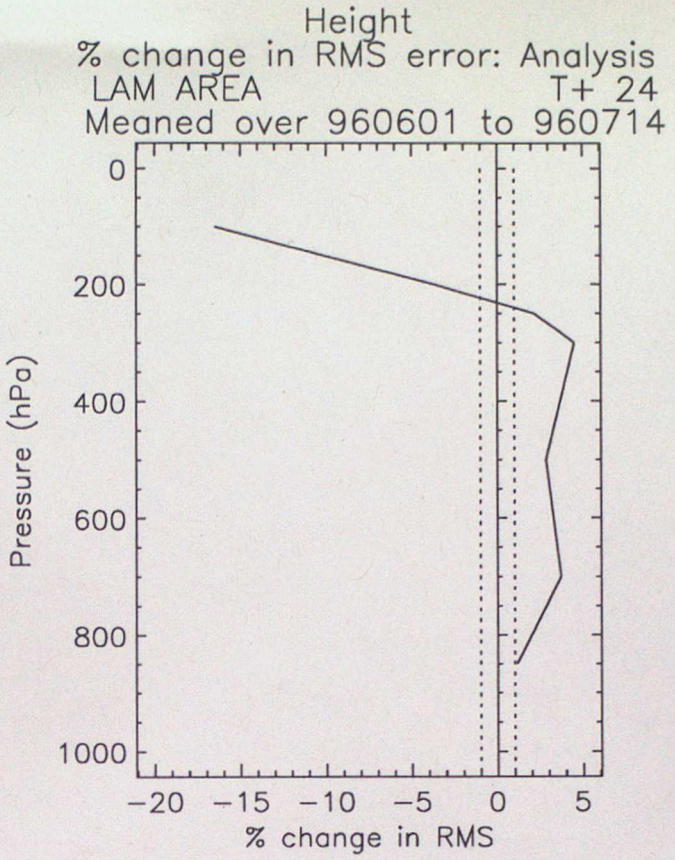

Temperature T at −1.000 meters
% change in RMS error:Surface
UK & ICELAND
Meaned over 960601 to 960714
% change in RMS error
Forecast Range
20
15
10
5
0
−5
0
5
10
15
20
25

FIGURE 4. 36


Height
% change in RMS error: Analysis
LAM AREA
T+ 12
Meaned over 960601 to 960714
Pressure (hPa)
0
200
400
600
800
1000
−15 −10 −5 0 5 10 15
% change in RMS


Height
% change in RMS error: Analysis
LAM AREA
T+ 24
Meaned over 960601 to 960714
Pressure (hPa)
0
200
400
600
800
1000
−20 −15 −10 −5 0 5
% change in RMS

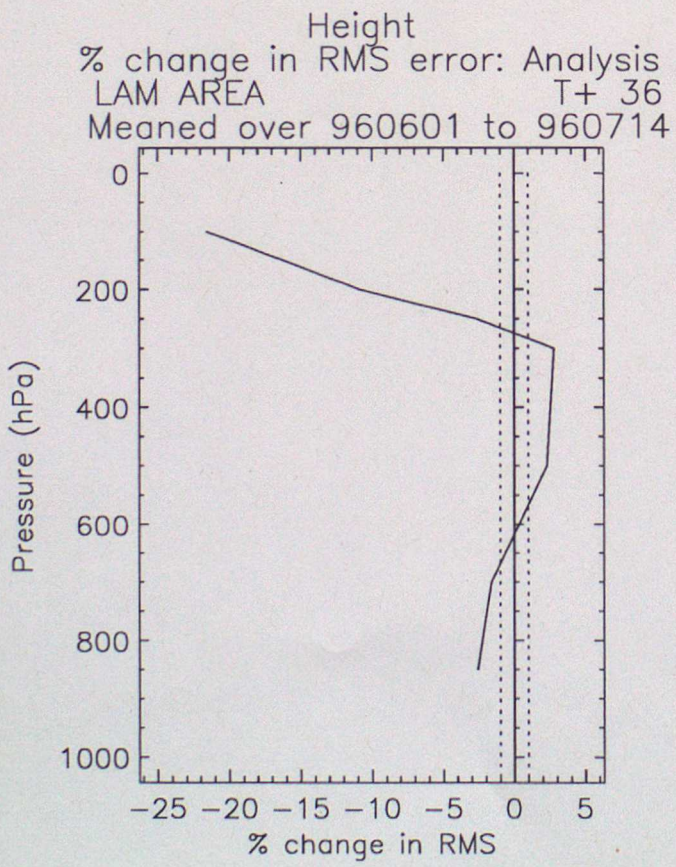
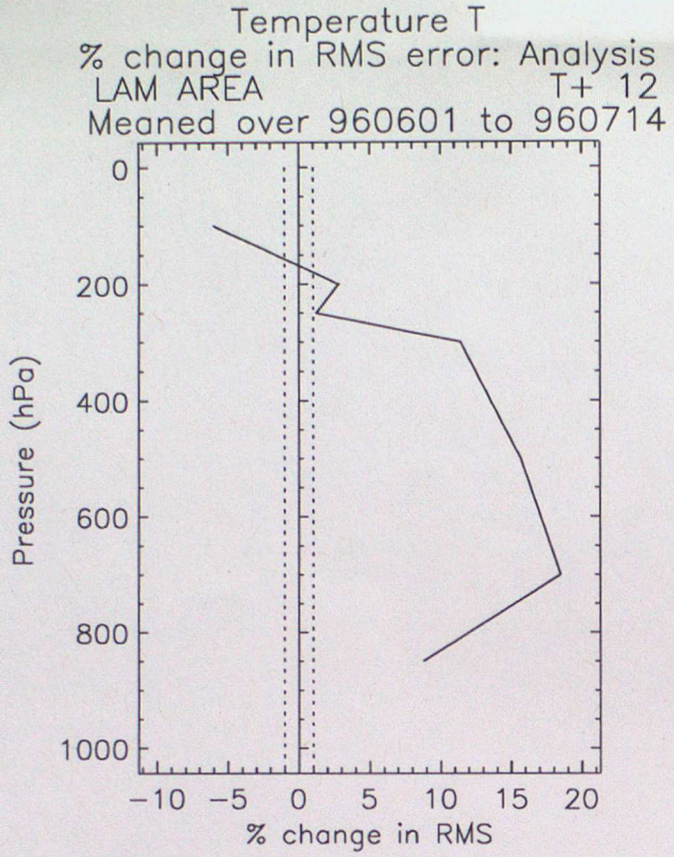
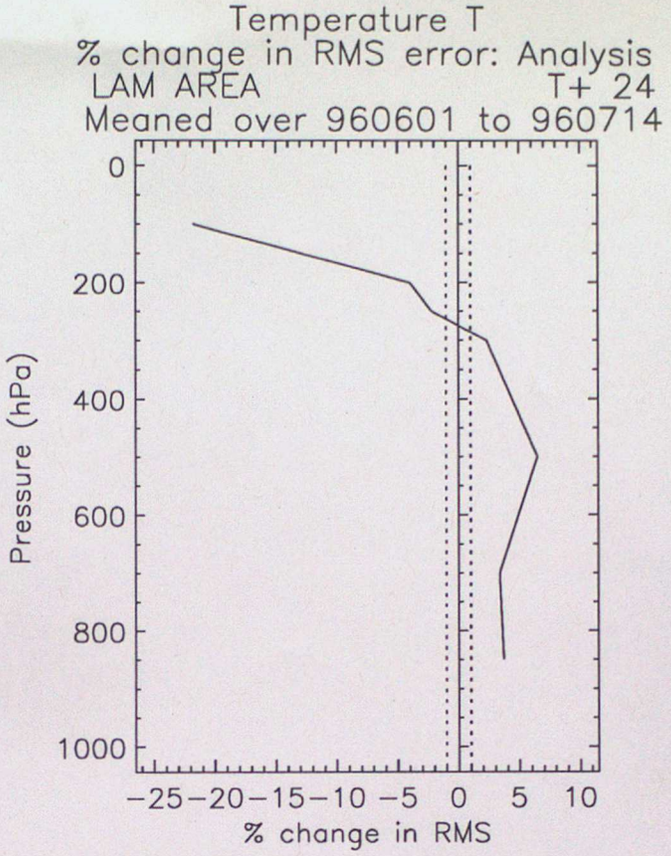

Height
% change in RMS error: Analysis
LAM AREA
T+ 36
Meaned over 960601 to 960714
Pressure (hPa)
0
200
400
600
800
1000
−25 −20 −15 −10 −5 0 5
% change in RMS

FIGURE 4. 37


Temperature T
% change in RMS error: Analysis
LAM AREA
T+ 12
Meaned over 960601 to 960714
Pressure (hPa)
0
200
400
600
800
1000
−10 −5 0 5 10 15 20
% change in RMS


Temperature T
% change in RMS error: Analysis
LAM AREA
T+ 24
Meaned over 960601 to 960714
Pressure (hPa)
0
200
400
600
800
1000
−25 −20 −15 −10 −5 0 5 10
% change in RMS

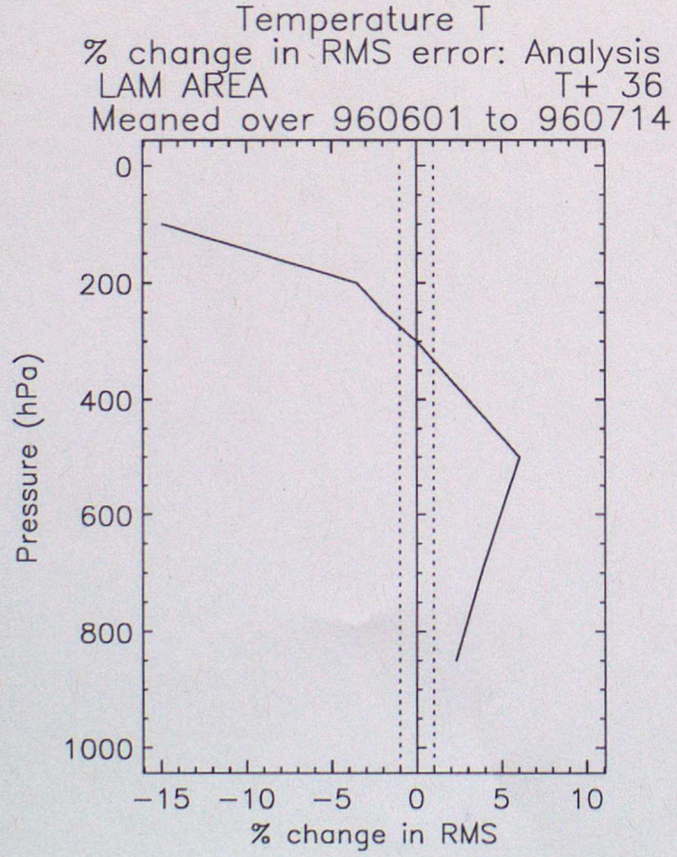

Temperature T
% change in RMS error: Analysis
LAM AREA
T+ 36
Meaned over 960601 to 960714
Pressure (hPa)
0
200
400
600
800
1000
−15 −10 −5 0 5 10
% change in RMS

FIGURE 4. 38

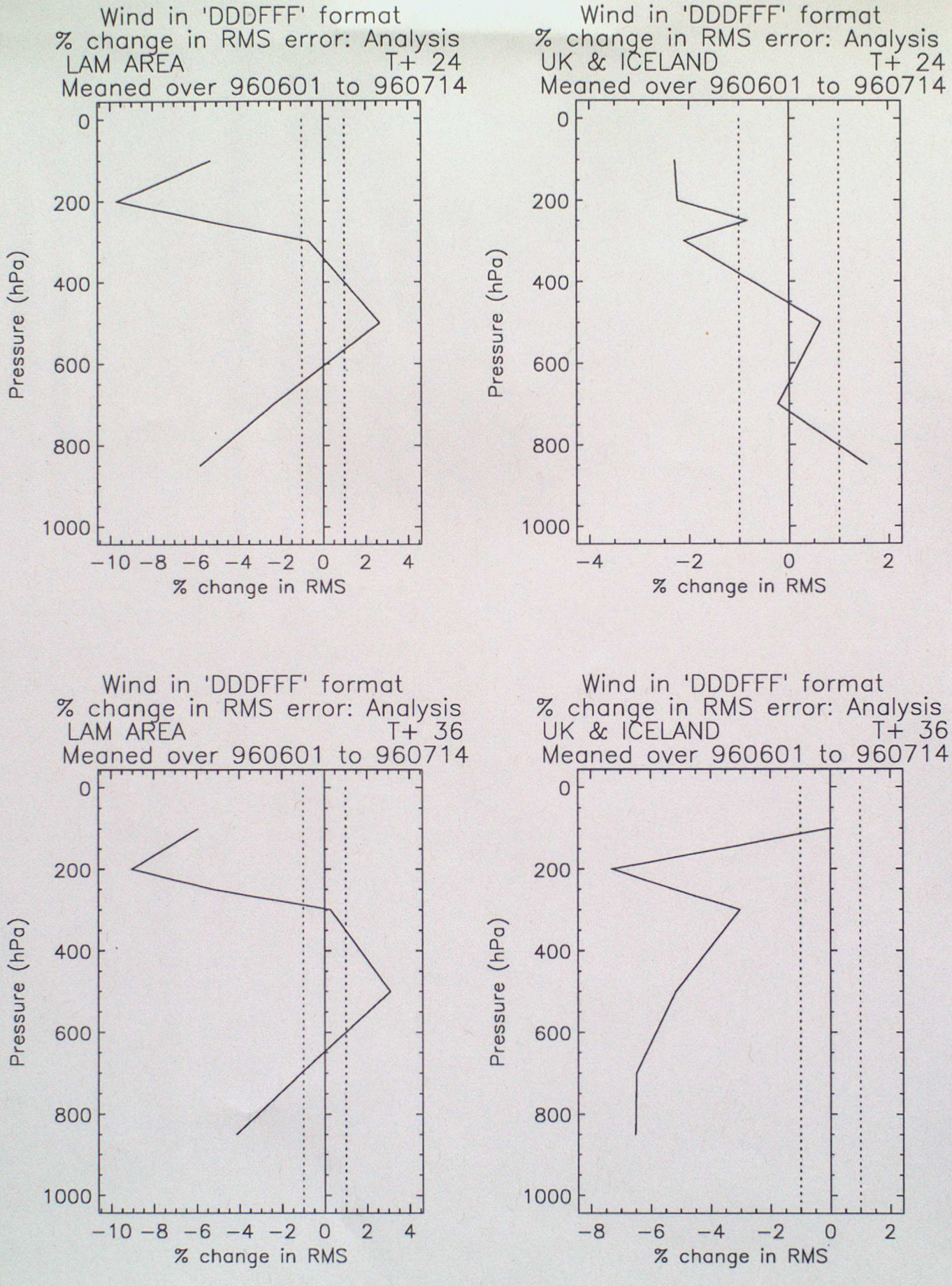
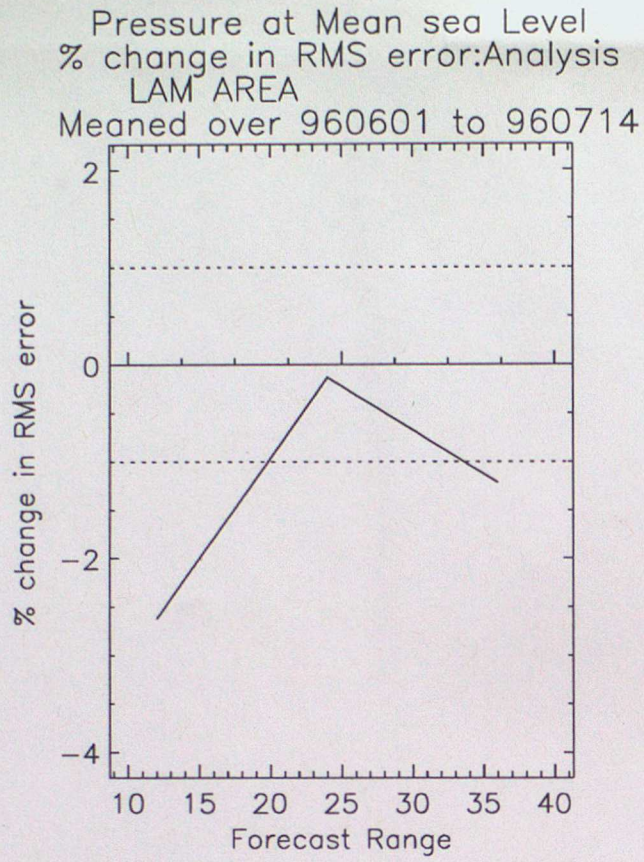
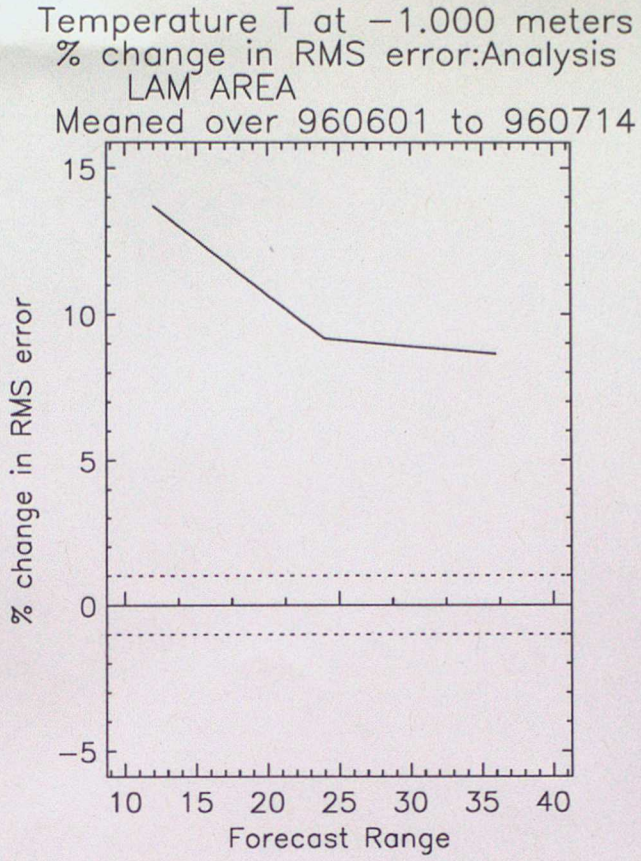

Wind in 'DDDFFF' format
% change in RMS error: Analysis
LAM AREA T+ 24
Meaned over 960601 to 960714
Pressure (hPa)
0
200
400
600
800
1000
−10 −8 −6 −4 −2 0 2 4
% change in RMS
Wind in 'DDDFFF' format
% change in RMS error: Analysis
UK & ICELAND T+ 24
Meaned over 960601 to 960714
Pressure (hPa)
0
200
400
600
800
1000
−4 −2 0 2
% change in RMS
Wind in 'DDDFFF' format
% change in RMS error: Analysis
LAM AREA T+ 36
Meaned over 960601 to 960714
Pressure (hPa)
0
200
400
600
800
1000
−10 −8 −6 −4 −2 0 2 4
% change in RMS
Wind in 'DDDFFF' format
% change in RMS error: Analysis
UK & ICELAND T+ 36
Meaned over 960601 to 960714
Pressure (hPa)
0
200
400
600
800
1000
−8 −6 −4 −2 0 2
% change in RMS

FIGURE 4. 39


Pressure at Mean sea Level
% change in RMS error:Analysis
LAM AREA
Meaned over 960601 to 960714
% change in RMS error
2
0
−2
−4
10 15 20 25 30 35 40
Forecast Range


Temperature T at −1.000 meters
% change in RMS error:Analysis
LAM AREA
Meaned over 960601 to 960714
% change in RMS error
15
10
5
0
−5
10 15 20 25 30 35 40
Forecast Range

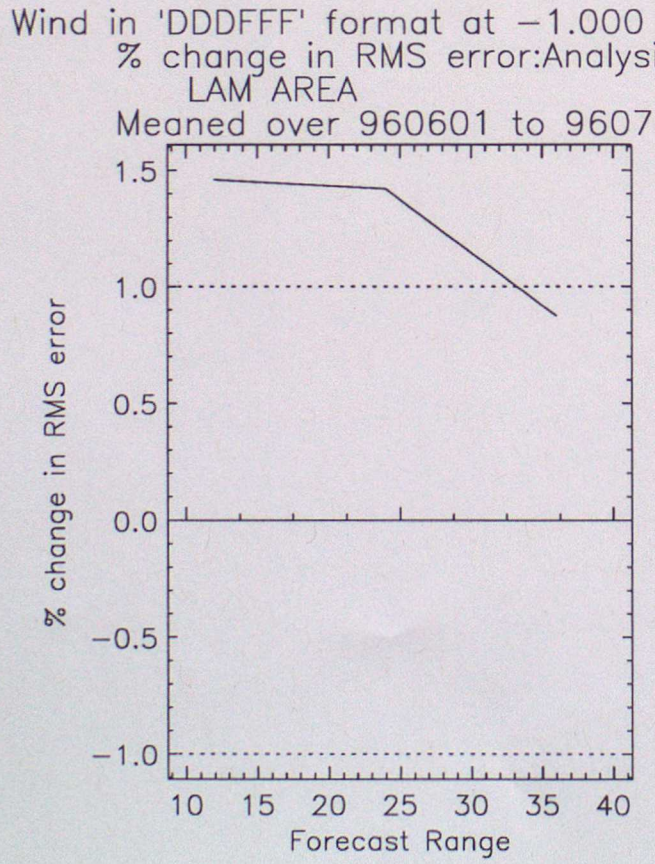
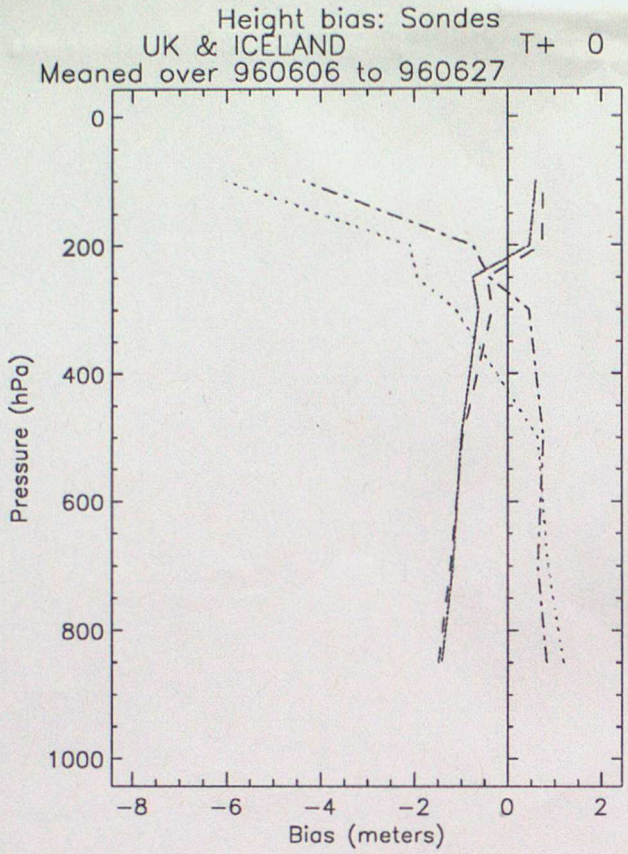
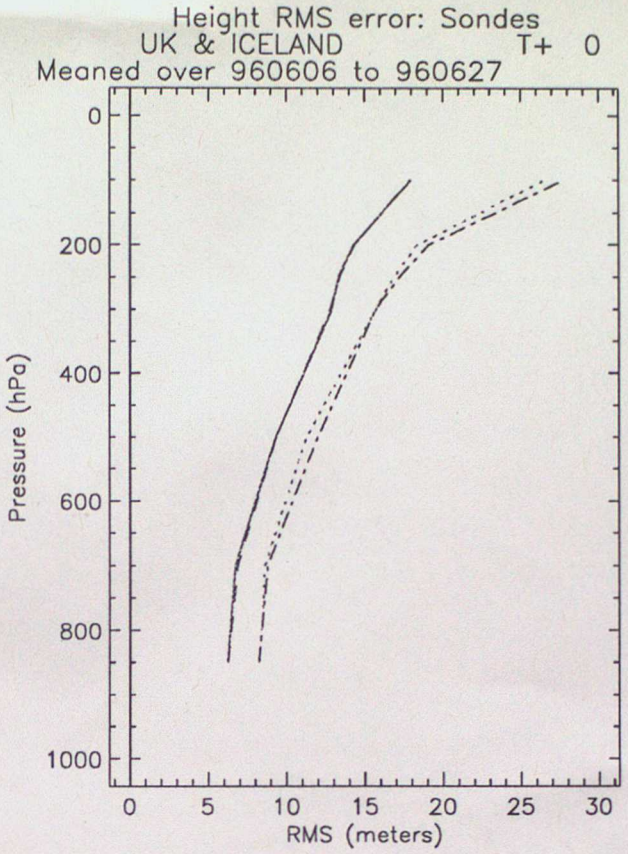
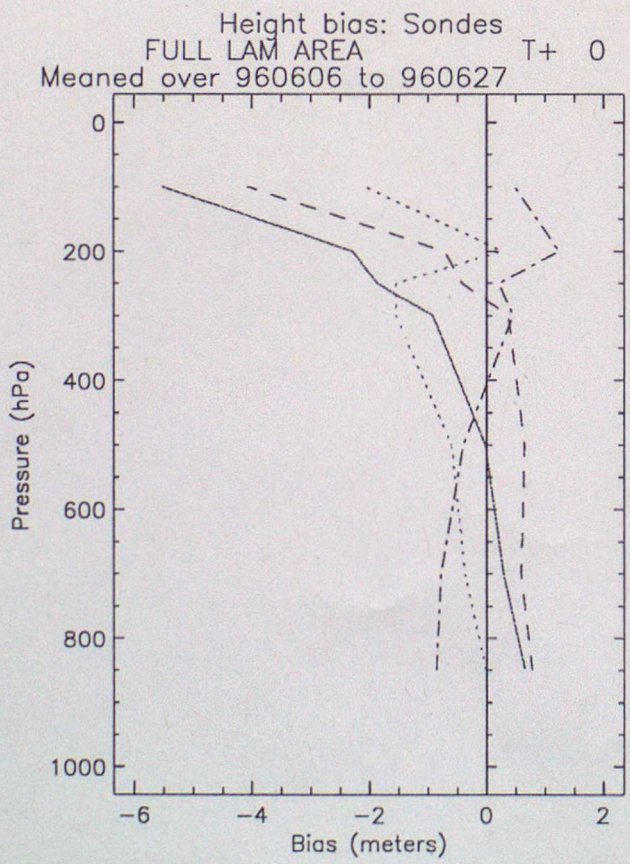

Wind in 'DDDFFF' format at −1.000 meters
% change in RMS error:Analysis
LAM AREA
Meaned over 960601 to 960714
% change in RMS error
1.5
1.0
0.5
0.0
−0.5
−1.0
10 15 20 25 30 35 40
Forecast Range

FIGURE 4. 40


Height bias: Sondes
UK & ICELAND T+ 0
Meaned over 960606 to 960627
Pressure (hPa)
0
200
400
600
800
1000
−8
−6
−4
−2
0
2
Bias (meters)


Height RMS error: Sondes
UK & ICELAND T+ 0
Meaned over 960606 to 960627
Pressure (hPa)
0
200
400
600
800
1000
0
5
10
15
20
25
30
RMS (meters)


Height bias: Sondes
FULL LAM AREA T+ 0
Meaned over 960606 to 960627
Pressure (hPa)
0
200
400
600
800
1000
−6
−4
−2
0
2
Bias (meters)

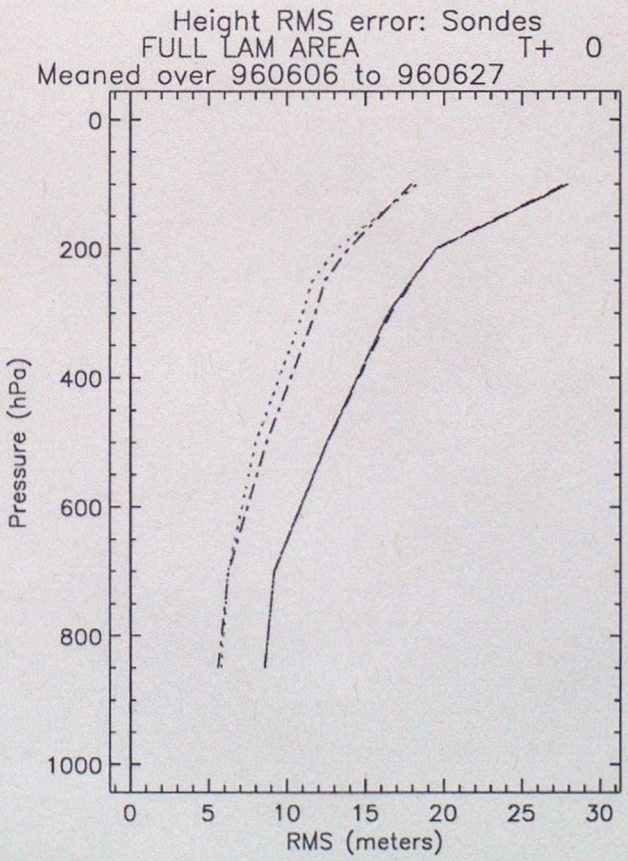

Height RMS error: Sondes
FULL LAM AREA T+ 0
Meaned over 960606 to 960627
Pressure (hPa)
0
200
400
600
800
1000
0
5
10
15
20
25
30
RMS (meters)

FIGURE 4. 41